EKSTRAPOLACIJA PODATAKA DOBIJENIH SA STANICE ZA VETAR KORISTEĆI IMPLEMENTACIJU CFD MODELA U OKVIRU WINDSIM SOFTVERSKOG PAKETA

EXTRAPOLATION OF THE MEASURED WIND DATA USING CFD MODEL IMPLEMENTED IN THE WINDSIM SOFTWARE PACKAGE

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Goal of this paper was to test the WindSim implementation of the CFD model and its ability to calculate wind speed for the complex terrain conditions present north of the National park Deliblato Sands. This area consist of a long cultivated sand dune west and complex hilly terrain formation on the east. Since this area was extensively monitored during the past decade, using the existing wind resource map idea was to extrapolate results from one measuring station to the location of the

Ključne reči: CFD model, ruža vetrova, predikcija resursa vetra, WindSim simulacija
second and vice versa by varying initial conditions of the CFD model. Intention was to show that the model will be capable of predicting the mean wind speed on the location of the second measurement pole using the measurement data from the first one within the range of the measurement uncertainty if the proper values for the initial conditions are selected. Distribution of the wind speeds was calculated based on the simulation of the air masses movement for the spring-summer measurement period on the height 30m above the ground. Obtained results will allow better understanding of the micro climate in this area which is necessary for the estimation of the wind resources.

**Key words:** CFD model testing, wind fields, wind resource prediction, WindSim simulation

**INTRODUCTION**

Following the current level of industrial growth and green house gasses emission, it is expected to cause the increase of the mean global as high as 6.4°C at the end of the 21th century. [1] Renewable energy resources, such as wind power, hydropower, tidal forces, geothermal energy, are offering solution for this eminent threat to our planet. It’s estimated that today energy production from wind power participate in the global energy production with 2.5%, [2] and that some countries such as Denmark, Portugal and Spain have about 15% - 20% of stationary electricity production from wind. [2] Serbia, on its path to become EU member, is planning to incorporate in its energy production renewable energy recourses, predominantly by introducing wind power and expanding hydropower capacities. At this moment, Serbia’s energy production from renewable energy resources is around 6%, mainly due to hydropower plants.[3] According to study made in 2002 [5] it was shown that Serbia’s capacity for wind power installment is 1300MW, which is around 15% of total power production in Serbia. Studies [4]–[9], were made during the last decade with a goal to map wind resources in Serbia, and create map of the average wind speed over the territory of Serbia. Conclusion of these studies is that the wind speed is greatest in Southern Banat region, and Vršac’s mountains region, and that these two regions have the biggest wind potential in the country. Map of the average wind speed over the territory of Serbia is presented in Figure 1.

Computational Flow Dynamics (CFD) is a numerical model for solving fluid dynamics equations. Model implemented in software package WindSimÔ is based on solving simplified Navier – Stokes equations or RANS (Reynolds-Averaged Navier–Stokes). RANS are time-averaged equations of motion for fluid flow. The main idea behind these equations is Reynolds decomposition, whereby an instantaneous quantity is decomposed into its time-averaged and fluctuating quantities. These equations can be used with approximations based on knowledge of the properties of flow turbulence to give approximate time-averaged solutions to the Navier–Stokes equations. In general this means that the non-linear part of these equations is transformed to be linear. Downside of this approximation is a significant influence on the results and its precision. [10], [11].
In case of complex terrains (steep heals with the inclination of \( >20^\circ \)) Linear Flow Model (LFM) cannot account for flow separation and turbulent air mass movement. Some software packages introduced methods for overcoming these limitations. E.g. WAsP, one of the most commercially used wind prediction software packages, tried to bypass this problem [12] by introducing ruggedness index (RIX). [13],[14] RIX is good solution that improves precision of the predicted results significantly over the complex terrains. On the other hand CFD method is more reliable and robust in case of flow split and turbulences, since it can account for these two effects directly, without additional parameters or factors in the simulation.

Wind speed simulation over some particular area is defined by a proper selection of boundary conditions at the borders of the area of interest and the height of the geotropic wind above the surface. Boundary conditions considered by WindSim software package are height at which the wind speed is considered to be constant, value of the speed at that height and boundary condition at top of the boundary level. The last parameter is related to terrain complexity. There are two selections for this parameter: fixed pressure, and nonfictional wall. First selection is better in case of hilly or mountain terrains and the second one are more efficient while predicting wind speeds over the fields, planes and grasslands. [15] Since the terrain at the “Šušara fields” is situated on the cultivated sand dyne and it’s mostly hilly, lacking any flat surface, better choice for this parameter was fixed pressure approximation.

Testing of the WindSim CFD model was performed by comparing measurement results of the wind characteristics gathered from two measurement stations located at Šušara fields with the wind speed simulation results provided by the software package. Applied model for simulation confirmation and determination of boundary conditions is used as a starting verification of the model competence. [16], [17] Variation of different values of the boundary conditions is used to project and predict expected wind field raster of the second measurement mast at location B, using wind speed data from the first measurement mast at location A and vice versa.
LOCATION OF MEASUREMENT STATION

Based on the wind speed estimation studies, Šušara fields locality is situated in the area with the greatest wind potential in South-East (SE) Banat. This locality represents a unique geo-morphological configuration shaped in a form of a 10km long and 500 m wide cultivated sand dune. This sand dune reaches heights from 40 m to 100 m above the surrounding plains. It’s situated at the northern border of the Special Nature Reserve (SNR) “Deliblato Sands”. Because of its geomorphological origin, as a relic of a former Pannonian sea, wind had great influence on its creation. Case measurement mast was positioned in the extremely hilly terrain in the locality of Zagajica hills (A), while the control one was positioned on the lower, more flat part of the dune (B).

Figure 3. Orography of the Susara (left) and measurement mast locations (right)

SENSORS

Hardware used in this field study of the wind potential over the Šušara fields’ locality consists of two 50 m tall measurement masts NRG TallTower. Both masts were equipped with four anemometers NRG #40C placed at heights of 30 m, 40 m, and 50 m. Along with the anemometers, two wind wanes NRG #200P were installed as well at heights of 30m, and 50m. Anemometers have 0.3 m/s offset and measurement error of ± 1%. For data transfer was used Symphonie iPackGPS (GSM/GPRS) data logger. Logged data consist of 10 minute median values and the standard deviation measured every 2 second during the 10 minute interval.

RESULTS

Data from measurement stations were gathered during the five year period. In this paper results will be presented based on a three month sample measurement from spring to summer 2010, so that the estimated roughness values correspond to the vegetation period. Data was first processed in OWC wizard (module of WAsP wind assessment tool). Results were wind roses for both masts. Using these wind roses, mean wind speed for the three month period at 30 m was predicted. For the masts A and B this speeds were 4.96 m/s and 4.70 m/s respectively. Also, they were used as a referent measured values that will be compared with the simulated wind roses from a WindSim simulation.
Simulation testing was performed by constantly changing values of the boundary conditions parameters. Inadequate selection of boundary conditions parameters led to incorrect predictions of wind fields over the locality. E.g., if the selected maximum height of the simulation is too high, simulation will not be able to account terrain effects on the wind fields, and if the maximum height is too low, small changes in the boundary conditions will produce significant fluctuations in the resulting wind fields. It was noticed that in some cases measured and predicted wind roses were almost the same, which is the proof that simulation didn’t manage to include terrain effects because of the inappropriate boundary conditions in Figure 5.

Also, this will have influence on the wind speed field’s prediction as well. Results presented in Figure 6 shows how inadequate parameters of the simulation will produce wind map that will have highest wind speed values even at the location of the mast B which has the lowest wind speeds at Šušara fields locality.

After many attempts, proper set of parameters was found providing prediction error of 1% - 2% for the mean wind speed during the period of measurement while predicting climatology on second site using the data from the first site. This means that mean wind speed prediction error is 0.05 m/s – 0.11 m/s and it is comparable to anemometers’ measurement error which is ± 1%. Results of a mean wind speed value prediction during the period of measurement are given in Table 1.
Figure 6. Wind field prediction at 30m, using inadequate boundary conditions. As a result wind fields with the greatest energy potential can be found near locality B as well, which is contradictory to measured data.

Table 1. Mean wind speeds at 30 m for the masts A and B (main diagonal of the table) and model predictions for the cases A→B and B→A respectively (other diagonal).

<table>
<thead>
<tr>
<th>MAST AND ITS COORDINATES</th>
<th>MAST A (30 m) x=514812.6 m y=4976275 m</th>
<th>MAST B (30 m) x=509947 m y=4978416 m</th>
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<tr>
<td>MAST A (30 m) x=514812.6 m y=4976275 m</td>
<td>4.96 m/s</td>
<td>5.07 m/s</td>
</tr>
<tr>
<td>MAST B (30 m) x=509947 m y=4978416 m</td>
<td>4.65 m/s</td>
<td>4.70 m/s</td>
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This type of testing is used for the first approximation of the model certainty. Based on the similarity of measured and simulated wind roses, it can be assumed that the used fluid dynamics model is satisfying, so the right set of the boundary condition parameters can be found. Simulation using these set of parameters will make insignificant error, comparable to instrument measurement error, while predicting mean wind speeds at 30m (Fig. 7).

Figure 6. Wind speed prediction over the Šušara fields locality at 30m above the ground. Area around the mast A has the greatest wind potential, while the area around mast B has the lowest.

Area of the Zagajica hills (location A) has the greatest wind potential within the borders of the Šušara field’s locality. On the other hand, location of the second
mast (location B) is less windy because of the influence of the local orography. Wind speed decreasing trend from SE to NW is evident, indicating that “Košava” is dominant wind in on this locality, which played an important role in the process of terrain formation of this locality throughout millennia.

CONCLUSION

Using Šušara fields locality as an example locality, preliminary testing of the WindSim CFD model was performed. CFD model was tested, since the locality consist of several areas of complex orography where linear fluid dynamic model would not be able provide good results. Mean wind speed from at the location of two measurement masts during the period data gathering was used as a comparison parameter for measured and simulated data. Relying on the brute force approach, proper set of boundary conditions and simulation parameters was investigated in order to find difference between transfer climatology derived from measured and simulated data at 30m height within sensor measurement error boundaries (>2%). Obtained results confirmed superiority of the CFD model in case of rugged complex terrains such is the case with Susara Fields at 30 m above the ground. Calculations confirmed that the measurement masts are approximately situated at locations with highest and lowest wind potential. These results are important for future wind power harvesting and climatology conditions analysis over the Šušara fields’ locality. Further model analysis will comprise of sector testing, and climatology extrapolation to different heights.

ACKNOWLEDGEMENT

The authors gratefully acknowledge financial support from the Ministry of Education and Science, Government of the Republic of Serbia through the Project No. 32043: “Development and modeling of energy efficient, adaptive, multi-processor and multi sensor low power electronic systems”.

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