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Wind Energy Prediction in Kosovo by WAsP11 software

***Abstract**. In the world, the capacities that use wind energy are increasing. Thus, these changes that develop in the framework of wind energy also require the development and accuracy of the forecast of the energy that can be produced. A main reason for this could be the fact that it is required to have stability in the energy network. In the field of wind energy, respectively the feasibility of wind farms, different software have been developed, some enabling 3D simulations and some linear simulations, without affecting the accuracy of the forecast. Various software advance in forecasting and this also increases the reliability of the analyzes carried out. This study analyzes the WAsP software, developed by DTU. This software is used for the purpose of analyzing the energy that can be produced at the output, the losses caused by the wake effect and so on. The place taken in the study is a complex mountainous terrain, in which the measurements were carried out for a year wind parameters at different heights, and the highest height is considered for the analyzes carried out here. The turbines used in the study are of the General Electric 3.6MW and General Electric 3.2MW types. The country being analyzed is in Kosovo, exactly Kitka, on the border with the neighboring state.*

Streszczenie.** W artykule analizowano możliwość wykorzystania oprogramowania WAsP WindSimulations do projektowania usytuowania farm wiatrowych w złożonym ukształtowaniu terenu. Możliwe było uwzględnienie turbulencji wiatru, obecność lasów, budynków etc.**Przewidywanie energii wiatrowej w Kosowie przy wykorzystaniu oprogramowania WAsP1

Keywords: Wind turbines, WAsP11, wind energy production, turbulence intensity, wake losses.
Słowa kluczowe: turbiny wiatrowe, oprogramowanie WAsP11

Introduction

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. The energy that can be captured by wind turbines is highly dependent on the local average wind speed.[1] Project is located at about 7km north of Kamenica city of Kosovo which is at the eastern part of Kosovo.

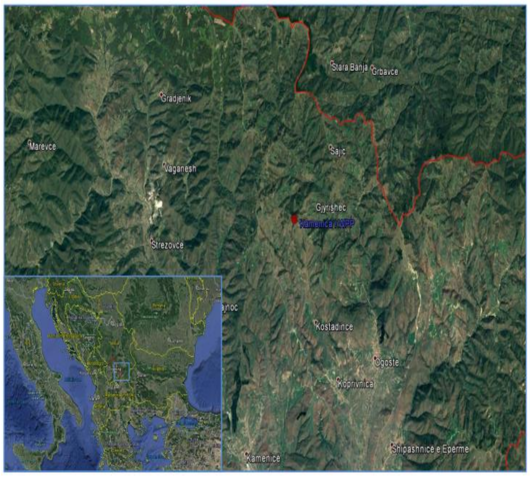

Fig. 1. View of a possible Kitka's wind park

Around the world, small wind energy is moving toward becoming a competitive alternative to power distributed generation. Two factors influence its development: policies to promote the technology and the costs of the systems.[2] In cases where we want to analyze a potential wind site, how exactly the potential can be reached and do not have accurate measurements, then they can be done through software. One possible software is WAsP as well. Most

commonly used for wind resource predictions on land as well as offshore is the WAsP program[3].

Dhunny et al. validated the application of WindSim in an island situation using two roughness lengths, one for land and one for sea. Waewsak et al. applied WindSim to a wind resource assessment study in Thailand and found good agreement between simulation results and met mast measurements. Finally, Teneler evaluated the forestmodelinWindSimandfoundthatmodelingtheforestasaporousmediumimprovedsimulation accuracy in heterogeneous forested regions [4].

Site consists of 7 units of GE3.6MW turbines and 3 units of GE3.2MW turbines. Turbines are located regarding wind potential, site accessibility, public land usage and private land usage.

Table 1: Main characteristics of two wind turbines types

Characteristics	**General Electric 3.2MW**	**General Electric 3.6MW**
Power	3200kW	3600kW
Hub Height	110m	110m
Rotor Diameter	130m	137m
Sweeping Area	53093 m^2	58965m^2
Tower	Tubular	Tubular
IEC Class	IIB (Medium TI)	IIIC (Low TI)
Power Curve Air Density	1.225 kg/m^3	1.225 kg/m^3

Wind data was measured at Kamenica, met mast from August 2017 to December 2017. When the public and commercial data sources were investigated only MERRA-2 data has been found available with concurrent measurement period.

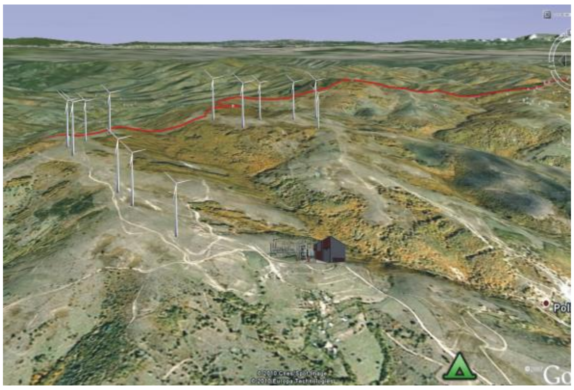

Fig. 2. Possible wind farm organized

Nowadays, in particular, wind energy is one of the fastest growing, cost-effective, lightweight, high efficiency and the environmentally accepted mean of electric power generation. Kitka (latitude: 42° 39' 56" (42.6656°) north, longitude: 21° 39' 36" (21.66°) east) is a mountain within Kosovo and is nearby to Lisacka and Hurugljica[5].

Each MERRA-2 dataset covers 20km x 20km meso scale area with 30 years of measurement period. Four sets of MERRA-2 data with different central locations were considered to be analysed, as we shown in figure 4.

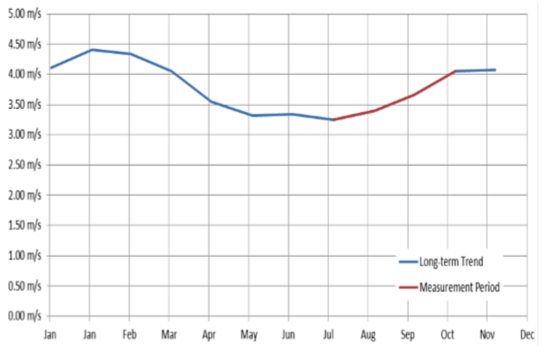

Fig. 3. Comparison of long term trend and measurement period of wind speed in Kitka

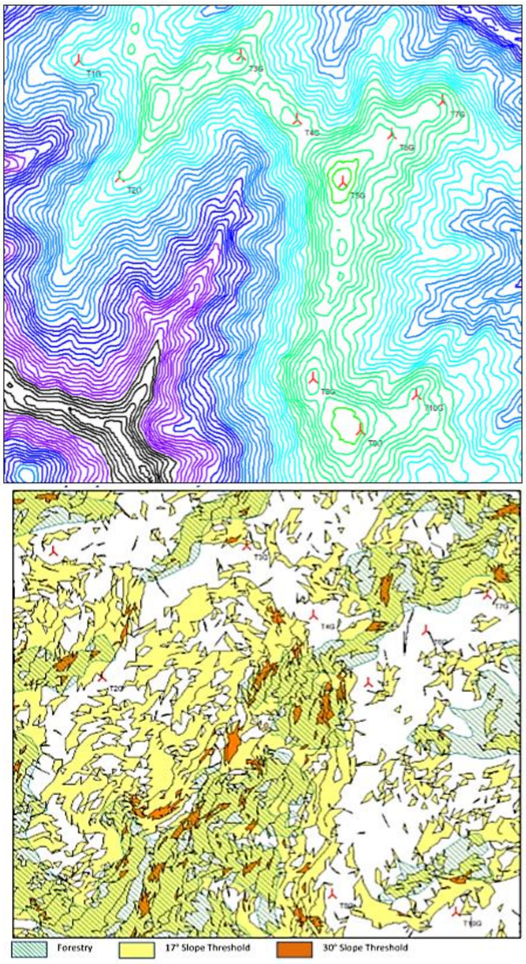

Fig. 4. Turbine's site topography, site slopes and forestry

Using normalized data from a certain range of wind conditions (hence, a larger dataset) allowed obtaining robust statistical results for a fair comparison. Another important point of view is wind rose at this location because we can see where is wind shared most in that place and speed of its.

Wind fields in mountainous regions are highly turbulent and are strongly modulated by local, nonlinear interactions with multi-scale surface heterogeneities.

The effects of wind-induced oscillations

Turbulence intensity and wind speed in estimating oscillation profiles can be directly obtained from measurements while turbulence propagation must be estimated implicitly.The structure of the turbine rotation subjected to oscillations is shown in the figure 6:

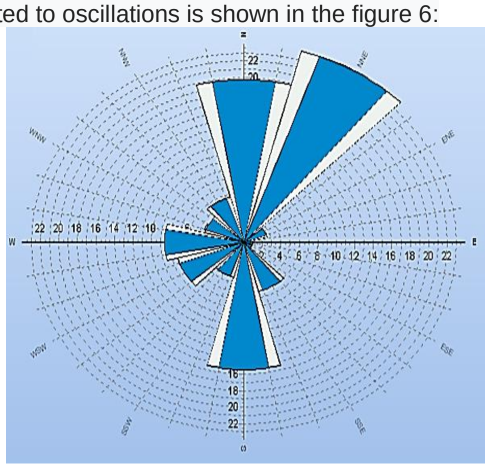
Fig. 5. Windrose in Kitka

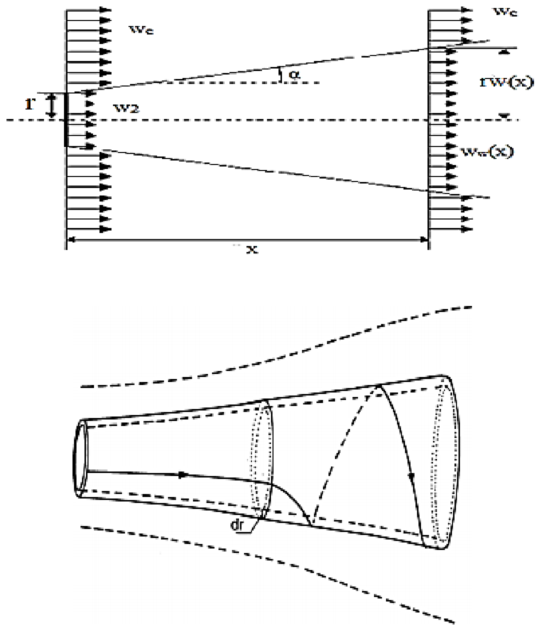

Fig. 6. Oscillations caused on a wind turbine rotor

Oscillations radius we can calculate by using below formule:

(1) $$r_w(x) = \chi \cdot x + r$$

Wind speed for a distance by x, in meters we can calculate with formula:

$$w_w(x) = w_0\left[1 - \left(\frac{r}{\chi \cdot x + r}\right)^2 (1 - \sqrt{1 - c_T})\right]$$

w_0 – wind speed in the before wind turbine rotor, m/s; w_2 – wind speed behind wind turbine rotor, m/s; rw (x) – is the radius obtained as a result of the change of wind speed at the distance x behind the rotor, r – wind turbine radius, m; χ – constants which describes changing of velocity behind wind speed, / ; c_T – coefficient of wind speed pressure, / w_w (x) – wind speed in a distance of x, m/s.

In WAsP the calculation of mutual wake effects between the turbines in a wind farm is based on a model described in the following figure.

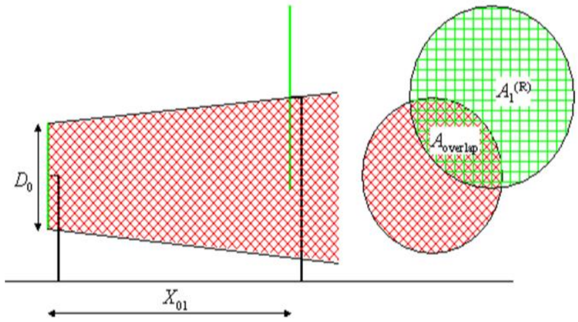

Fig. 7. The calculation of mutual wake effects between the turbines in a wind farm

(2) $$w_{01} = w_0 \cdot (1-\sqrt{1-C_T}) \cdot \left(\frac{D_0}{D_0 + 2 \cdot y \cdot X_{01}} \right)^2 \cdot \frac{A_{overlap}}{A_1}$$

The CT impulse coefficient is related to the FT impulse force for the model in question, and ρ being the density of air, is defined as [6]:

(3) $$C_T = \frac{2 \cdot F_T}{\rho \cdot \frac{\pi}{4} \cdot D_0^2 \cdot w_0^2}$$

Turbulence intensity is given as the ratio between the standard deviation of the wind speed in the horizontal direction and the mean wind speed [7]:

(4) $$TI = \frac{\sigma}{w_{ave}} \text{ in \%}$$

where σ, is standard derivation, given by next formula:

(5) $$\sigma^2 = \frac{1}{N-1} \cdot \left[\sum_{i=1}^{u} (w_i - w_{ave})^2 \right]$$

(6) $$\sigma = \sqrt{\frac{1}{N-1} \cdot \left[\sum_{i=1}^{u} (w_i - w_{ave})^2 \right]}$$

These programs are based on different mathematical models for calculating the effects of wind speed change and include different studies as Lissman, Jensen etc.[8].

In order to study all of those parameters such as wake losses and turbulence first we can see the mean wind speed in this area of wind farm, measured in 4th different highness, first 40m, 60m, 80 and 84m[9].

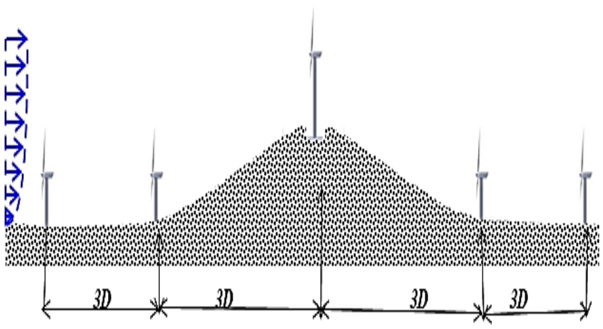

Fig. 8. 3D modelling of Kitka's wind farm

Wake effects have been calculated by N.O Jensen Wake model. Park efficiency of 95.4% is achieved. Turbines are not observed to be aligned in prevailing wind direction and in non-prevailing wind direction horizontal distances are considered suitable.

Turbine availability of 97.0% is assumed as the warranted availability of the expected service agreement.

Balance of plant availability is considered as 99.8% and grid availability is considered as 99.5%. Total electrical efficiency is expected to be 98%. It is noted that electrical design should be done in this regard.

Table 2. Average wind speed in different highness in Kitka Wind Park

Data	84m	80m	60m	40m
Average per year	6.671	6.642	6.44	5.92

Environmental losses –The factor of shutdown due to icing, lightning, hail, etc. is assumed to be 99.3%. Shutdown due high and low temperature is not expected. Site access and other force majeure events have not been considered. Tree growth or felling has not been considered. Curtailment due to wind sector management, noise, flicker, birds and bats have not been considered.

Table 3. Totally losses on Kitka Wind Park

Losses	Losses (%)	Losses (GWh/yr)
1.Wake effects, all WTGs	4.61	5.7
2. Availability		
Turbine availability	3	3.7
Balance of plant (Substation)	0.5	0.6
Grid availability	0.2	0.2
3.Turbine performance	0.8	1.0
4. Electrical losses	2	2.5
5. Environmental		
Performance degradation due to icing	0.7	0.9
High and low temperature	0.3	0.4
6. Curtailment	/	
Total of losses	11.6	14.2

Wind Energy Production During Year

WAsP analyzes the orography and the site ruggedness index (RIX) of the entire grid layout. The associated performance indicator (ΔRIX) can identify problematic sites within a project [10].

The turbulence interaction between wake and outer flow is expected to be closely linked not only with the turbulence levels of the outer flow, but also with the structure of the turbulence. This is inspected via the velocity spectra, and real-space autocorrelations at various locations downwind of the model turbine [11].

Table 4. WTG sites and RIX values for all of them

Links	Easting	Northing	Z(m)	Reference Site RIX(%)	WTF RIX (%)	Delta RIX (WTG)
1A	544918	4726483	966.6	14.4	21.9	7.5
2A	545205	4725695	1000.0	14.4	22.2	7.8
3A	546034	1726525	1039.0	14.4	16.6	2.2
4A	546423	4726094	1019.9	14.4	17.3	2.9
5A	546741	4725671	1090.0	14.4	18.7	4.3
6A	547076	4725999	1060.0	14.4	17.2	2.8
7A	547427	4726226	1031.8	14.4	18.5	4.1
8A	546545	4724341	1070.0	14.4	18.9	4.5
9A	546878	4723993	1080.0	14.4	17.1	2.6
10A	547258	4724234	1040.0	14.4	18.0	3.6

The gross energy production of each turbine is calculated with WAsP v11 software. Afterwards estimated losses and uncertainties were considered. The predicted long-term mean wind speeds for each turbine hub height and regarding gross annual energy productions are listed below.

Table 5. The predicted long-term mean wind speeds for each turbine hub height and regarding gross annual energy productions

No	Easting	Northing	Z [m]	Turbine	Hub height [m]	Wake Efficiency [%]	Mean wind speed [m/s]	Air density [kg/m³]	Result Gross [MWh]	Result With Wake Effects [MWh]
T1G	544,918	4,726,483	967	GE 3.2 130	110	98.52	6.75	1.112	10,827	10,667
T2G	545,205	4,725,695	1,000	GE 3.6 137	110	96.77	6.77	1.108	12,077	11,687
T3G	546,034	4,726,525	1,040	GE 3.6 137	110	97.37	7	1.104	12,781	12,445
T4G	546,423	4,726,094	1,020	GE 3.6 137	110	96.81	7.02	1.106	12,802	12,394
T5G	546,741	4,725,671	1,090	GE 3.2 130	110	91.94	7.06	1.098	11,689	10,747
T6G	547,076	4,725,999	1,060	GE 3.2 130	110	93.16	6.97	1.101	11,422	10,641
T7G	547,427	4,726,226	1,032	GE 3.6 137	110	95.67	6.89	1.105	12,403	11,866
T8G	546,545	4,724,341	1,070	GE 3.6 137	110	95.48	7.11	1.1	13,140	12,547
T9G	546,878	4,723,993	1,080	GE 3.6 137	110	93.83	7.2	1.099	13,444	12,615
T10G	547,258	4,724,234	1,040	GE 3.6 137	110	94.4	6.86	1.104	12,298	11,609
								SUM	122,883	117,216

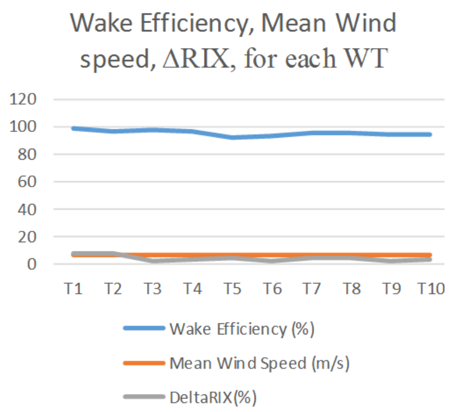

Fig. 9. Annual Energy Production from ten wind turbines, based on WAsP software

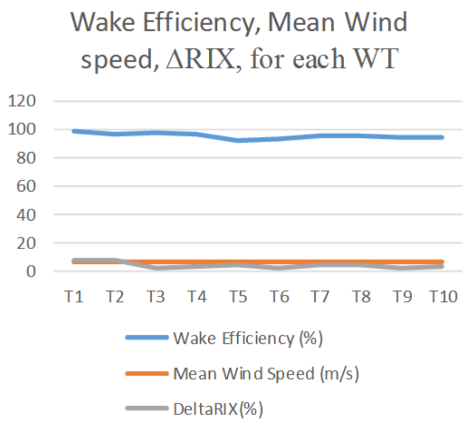

Fig 10. Wake efficiency, mean wind speed and total energy production

Conclusion

The analyzed terrain, Kitka, represents a place with a high capacity of wind energy, which is proven by the fact of the values that have resulted for the possible annual energy produced. But another element is that the compact terrain is present and this is observed by the values of RIX and dRIX for each possible position of the turbines that make up the wind farm in Kitka.

It can be concluded that:

1. It is possible to use such software in this terrain even though it is moderately complex terrain.
2. The output data taken from this software are less reliable than those in real measurement stations.
3. In order to know the role of implementation and the reliability of this software, WAsP11, a possible comparison of this software with another software, such as CFD and the like, can be made.

Another comparison can be made with the predicted energy and what is in real conditions, taking into account that this wind farm is in operation.

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