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Investigation of wind flow turbulence and energy parameters

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The research presents modelling results of incident wind flow through two wind turbines designed in connection in a series. The mathematical modelling variation of wakes of wind turbines has been performed. The model was used for wind flow in upstream and downstream directions. Derivations of assignments are presented in an experimental mode and with the help of the numerical PHOENICS model. The impact of turbulent wind flow on the energy production parameters has been estimated. Instantaneous wind flow turbulent impulses generated by wind turbines, influence the amount of generated energy and wind turbine alterations. Designing wind turbines and its parks, it is required to keep the distance between turbines in order that the same amount of wind flow falls to all wind turbines. Keeping the distance, a sufficient amount of wind energy falls to all wind turbines and the ground area is used rationally.

The wake interaction of wind flow through wind turbines, the influence of ground surface conformation on the deformation of wind velocity profiles and energy parameters has been assessed.

Key words: turbulence, numerical simulation, wind flow energy parameters

1. INTRODUCTION

The wind flow turbulence impulse modifies the amount of generated energy and influences changes in wind turbine (further WT) operation. It is obvious that designing WT parks and their position it is necessary to keep the distance between each WT in all directions. Wind flow before a next WT must be restored to the same amount [1–3] as before the first one, to ensure that the neighbouring WT will take an identical amount of kinetic energy accumulated in the wind flow. It is also necessary to measure wind flow parameters, to assess the ground surface relief, the variation of atmosphere boundary layer characteristics on the ground surface, turbulence level and other wind flow parameters [2]. The turbulence is one of wind flow characteristics that come into play on the WT blade boundary layer and effects the rotor torsion torque. The main reason for turbulence to appear is location obstacles and the relief near a WT. The generated dynamical pulsation of turbulence affects the flow over the WT blades and influences generation of energy [3–6].

Investigations on wind flow parameters while over-flowing various obstacles and WT are not numerous. Therefore it is necessary to analyse wind flow parameters and numerical modelling in a rough relief to determine WT operation parameters according to flow turbulence level and other flow parameters.

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2. OBJECTS AND METHODS

The main object of this research is to investigate the impact of wind flow turbulence pulsation on the WT operation regime, because an increased turbulence level in WT farms has an influence on production of energy. The research was carried out using the numerical modelling and experimental measurement methods. The aim of the study was using the numerical PHOENICS code to implement an elliptic model that describes wind flow through WT and its flow in WT wakes.

Another aim was to analyse and compare the numerical model calculation results with theoretical and experimental measurement data.

Wind flow profiles in the wake are set to be 0.25 of index dependence (it is treated as parabolic) that location considered to be reached at about 2D (two diameter) distance [3]. For further investigation it is intended to use a three-dimensional elliptical model that assess the closure of the turbulent flow, axial pressure gradient, convection and diffusion flow effects.

Because of the length and time scale variations in the turbulence flow diapason, it is advisable to use models of turbulence those static modelling surface layer [4, 5].

A specific system of coordinate axes was used: the *z*-axis represents the direction of the incident wind flow and the *y*-axis – in vertical ordinate.

For calculations, there were accepted the following assumptions:

– in a 2D distance before WT the wind flow profile is parabolic;

– the impact of the Coriolis forces is neglected;

– the turbulent transport coefficients are modelled using the k-ε method [5];

– because of symmetry, calculated is only half of the flow in wind-turbine wakes;

– steady density variation.

Regarding the boundary conditions and the formulated task, a system of elliptical equations is made, consisting of velocity components, turbulence kinetic energy and dissipation velocity of kinetic energy.

For modelling in the numerical PHOENICS code, three-dimensional transport process equations were used. The equations describing the flow in the wake are the conservation equations of mass, momentum, turbulent kinetic energy, and dissipation rate of the turbulent kinetic energy. The equations in general can be written as follows [5]:

$$S_\phi = \mathrm{div}\left(\rho \cdot \overline{\mathrm{V}} \cdot \phi - \Gamma_\phi \cdot \mathrm{grad}\phi\right), \qquad (1)$$

where ϕ is any dependent variable which can be equal to 1, or to one of the conserved characteristics, ν_ϕ is the turbulent diffusion coefficient, and S_ϕ is the source term. The rest variables are specified in the nomenclature section. Above written equation derivates laminar wind flow in a wake when it is applied for specific period. The turbulent flow equations are in average according to time scale. The general exchange coefficient is equal to the sum of laminar and turbulent flow coefficients [5]:

$$\Gamma_\phi = \Gamma_{l,\phi} = \nu_l/Pr_{l,\phi} + \nu_t/Pr_{t,\phi}, \qquad (2)$$

where

$$\nu_t = C_\mu k^{0,5} l, \qquad (3)$$

$$l = C_D k^{1,5}/\varepsilon, \qquad (4)$$

$$Pr_{l,u} = Pr_{l,v} = Pr_{l,w} = Pr_{l,k} = Pr_{l,}\varepsilon = 1,\ Pr_{t,u} = Pr_{t,v} = Pr_{t,w} = Pr_{t,k} = 1,\ Pr_{t,}\varepsilon = 1.3, \qquad (5)$$

where C_μ = 0.03, constant of the k-ε model, k is the turbulent kinetic energy, u, v, w are the variable velocity components for the Prandle number, and other variables are specified in the nomenclature section.

On a smooth surface a primary wind flow profile could be calculated by dimensionless correlations [6]:

$$U(y) = A\left(\frac{y}{\Delta h}\right)^{\frac{1}{4}}, \qquad (6)$$

where the constant A = 2.6; Δh is the step of differential mesh by vertical direction as the mean wind flow velocity in a wake is 5 m/s; A = 4.0 as the mean wind flow velocity is 8.5 m/s.

3. MODELLING RESULTS

The overflowing velocity profile depends on the analysed regional value by the vertical H. Regarding the above-mentioned equations and the proposed numerical calculation model, while investigation was obtained mesh of two WT aligned with the wind flow, and the distance between WT is designed of 5D (Fig. 1). Because of symmetry, only half of the trace section was calculated.

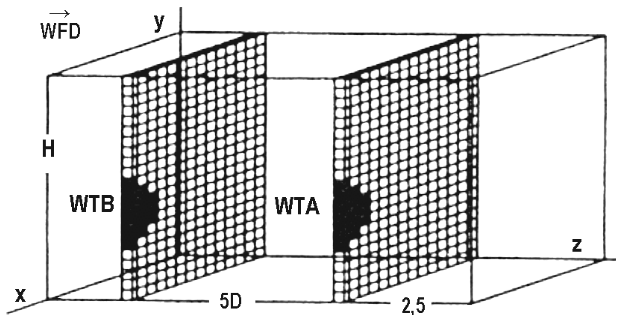

Fig. 1. Mesh and volumetric zone for two WT aligned by *z* coordinate and with the wind flow

The relative position and overflowing of two WTs aligned with the wind flow and the corresponding measuring masts M1, M2, M3 and M4 are shown in Fig. 2, where the distance between the masts varies: 2.5D, 1.5D, 1D, 1D and 1.5D.

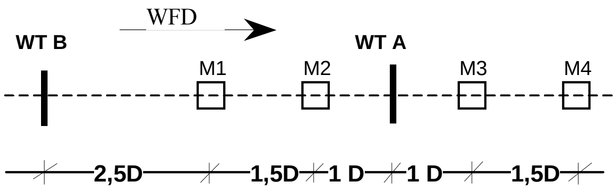

Fig. 2. Relative modelling position of two WTs

The diameter of each WT rotor is 40 m, and the rotor axle is 45 m above the ground. For further calculations and modelling, the following data have been chosen: the drag coefficient of 0.82, the

Monin–Obuchov length L = 161 m, ground surface roughness y_0 = 0.08 m, and the turbulence intensity at rotor heigh Tu = 0.125 (12.5%). The rectangular grids are 14 × 22 × 40, 14 × 22 × 40 and 20 × 22 × 40 (NX × NY × NZ). At the same time as two WTs are operating the wind flow wake trace interacts by wind flow direction.

The variations of kinetic energy in wind flow when the ground surface is flat (Fig. 3) and when the obstacle before WT is designed (with rough surface) are shown in Fig. 4. One can see that the designed obstacle causes wind flow deformations near the WT wake zone. A conspicuous decrease of

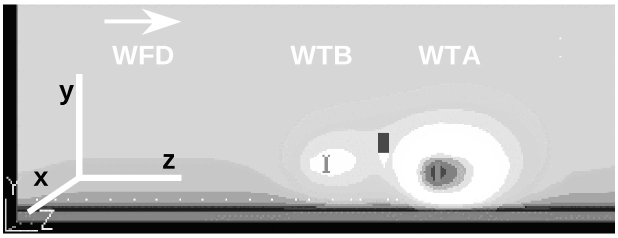

Fig. 3. Kinetic energy when ground surface is flat

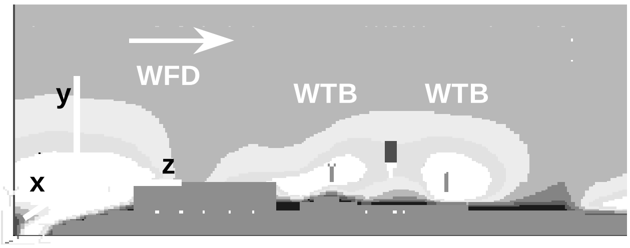

Fig. 4. Kinetic energy when ground surface is rough

wind flow velocity corresponds to the produced energy amount.

Figure 5 shows dimensionless mean wind velocity profiles in the vertical plane at the turbines high as the distributions in a vertical plane of mean wind velocity, divided by steady wind velocity (8.5 m/s) at the turbines high for measuring masts and different modelling sections.

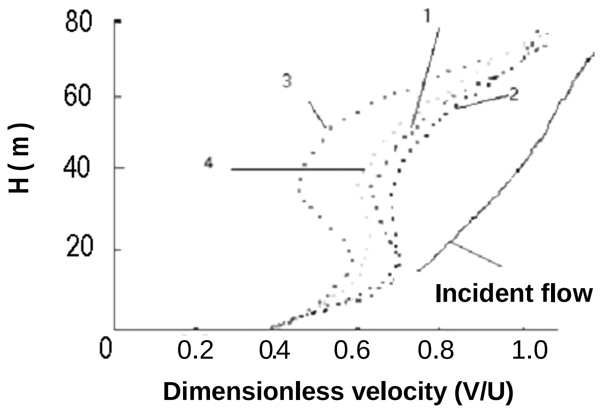

Fig. 5. Variation of dimensionless wind velocity profiles in different modelling sections

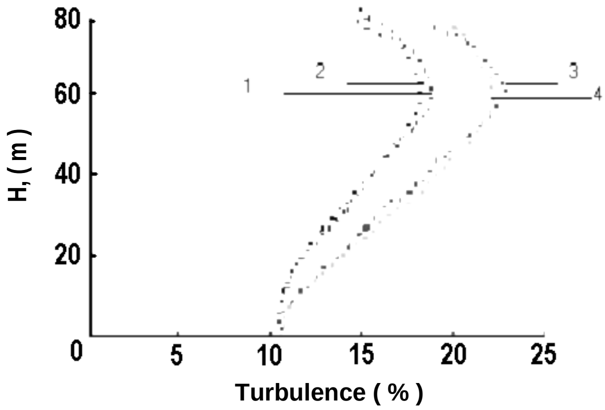

Fig. 6. Comparison of turbulent flow profiles in different modelling sections

Wind flow turbulence profiles (Fig. 6) show that the intensity of turbulence is higher in the section where two wakes interact (sections 3 and 4) than in the upstream region (sections 1 and 2).

Horizontal dimensionless wind flow velocity profiles, in different modelling sections when WTs are designed in perpendicular plane to wind flow direction are given in Fig. 7.

The velocity calculations made in perpendicular plane to wind flow velocity profiles, retired from WT by 2.5 D, 5.0 D, 7.5 D and 10.0 D distance. One can see that at a 2.5 D distance from WT the wind flow velocity profile is particularly deformed, and at a 10.0 D distance the velocity profiles become more steady. The whole velocity profile alignment is obtainable at a distance of 20D.

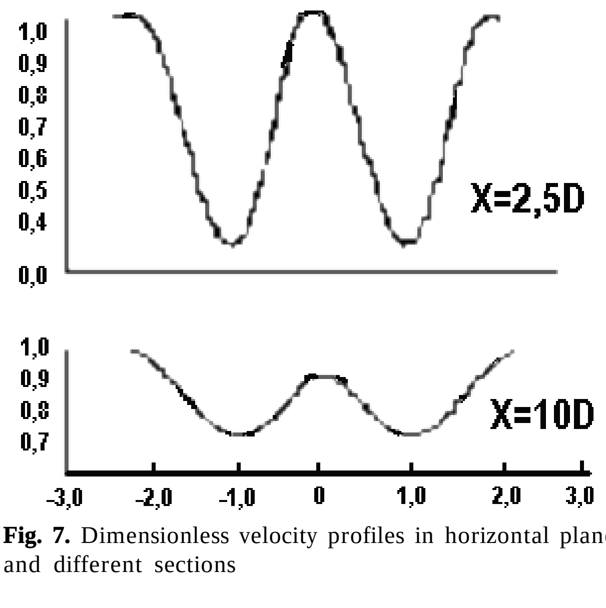

Fig. 7. Dimensionless velocity profiles in horizontal plane and different sections

4. CONCLUSIONS

1. Awaken flow interferences from WT and for numerical turbulence modelling and analysis were used three-dimensional transport process equations with the help of PHOENICS code.

2. The results of modelling show that for an efficient WT operation it is essential to construct it at a distance of 5D–12 D.

3. The implemented numerical model and experimental research show that wind energy conversion into WT mechanical energy depends on the turbulence value of air, which in turn depends on ground surface roughness. With increasing those values the conversion coefficient decreases.

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NOMENCLATURE

S_ϕ – derivation term (source term) for variable ϕ;

ϕ – any dependent variable can be equal to 1, or to one of the conserved characteristics;

ν_ϕ – turbulent diffusion coefficient;

div – differential operator;

ρ – air density, kg/m^3;

Γ_ϕ – general exchange coefficient of laminar and turbulent flow;

grad ϕ – gradient of ϕ variable;

$\bar{v}$ – velocity vector, m/s;

Tu – turbulence intensity;

ν_t – turbulent viscosity, m^2/s;

L – Monin–Obuchov length;

y_0 – ground surface roughness;

$C_\mu \cdot C_D = 0.09$;

$C_\mu = 0.03$, constant of the k-ε model;

k – turbulence kinetic energy;

l – length scale of turbulence, m;

ε – dissipation velocity of kinetic energy;

Constants of turbulence model (figures of Prandle for variables *u*, *v*, *w*, *k*, ε; l – laminar, *t* – turbulent):

$\boldsymbol{Pr_{l,u}} = Pr_{l,v} = Pr_{l,w} = Pr_{l,k} = Pr_{l,}\varepsilon = 1$; $\boldsymbol{Pr_{t,}}\varepsilon = 1{,}3$; $\boldsymbol{Pr_{t,u}} = Pr_{t,v} = Pr_{t,w} = Pr_{t,k} = 1$;

U – wind flow velocity at WT rotor's axle height;

V – velocity as *y* function, m/s;

A – constant (2.6; 4.0);

Δh – step of differential mesh by y coordinate direction;

D – diameter of WT rotor blades;

WTA and WTB – location of wind turbine rotor blades;

WFD – wind flow direction;

H – area high;

M – measuring mast;

x, *y*, *z* – Cartesian coordinates.

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VËJO SRAUTO TURBULENCIJOS IR ENERGETINIØ PARAMETRØ TYRIMAS

S a n t r a u k a

Pristatomi dviejø vëjo elektriniø aptekëjimo skaitinio modeliavimo rezultatai. Uþduoties sprendiniai pateikti pasitelkiant PHOENICS skaitinio modeliavimo programà, kuria imituotas vëjo srauto parametrø kitimas, aptekant vëjo elektrines pasroviui ir statmenai srauto krypèiai. Pastebima turbulencinio vëjo srauto tekëjimo átaka vëjo energijos parametrams. Vëjo elektriniø sukeliami momentiniai srauto turbulencijos impulsai turi átakà generuojamos elektros energijos kiekio ir vëjo elektriniø darbui. Projektuojant vëjo elektriniø parkus, tarp vëjo elektriniø reikia iðlaikyti atstumà, kad prieðais sumontuotø vëjo elektriniø panaudotas vëjo energijos kiekis spëtø atsistatyti. Tokiu bûdu laikantis nustatyto atstumo, projektuojamoms vëjo elektrinëms pakankamai tektø vëjo srauto energijos ir numatomas uþstatyti þemës plotas bûtø racionaliau naudojamas.

Modeliuojant nustatyta vëjo srauto bangø tarpusavio sàveika aptekant vëjo elektrines ir þemës pavirðiaus struktûros daroma átaka vëjo greièio profiliø deformacijai bei energijos parametrams.

Raktaþodþiai: turbulencija, skaitinis modeliavimas, vëjo srauto energetiniai parametrai

Эвальдас Биргиолас, Владисловас Катинас

ИССЛЕДОВАНИЕ ТУРБУЛЕНЦИИ И ЭНЕРГЕТИЧЕСКИХ ПАРАМЕТРОВ ПОТОКА ВЕТРА

Р е з ю м е

Представлены результаты математического моделирования обтекания потоком ветра двух ветроустановок. Выполнено математическое исследование турбулентного следа ветроустановок, плоскость ротора которых ориентирована перпендикулярно и последовательно направлению потока ветра. Интерпретация полученных результатов исследования произведена с использованием численной модели PHOENICS. Представлены расчетные данные влияния турбулентности потока ветра на энергетические параметры. Также учтены взаимодействие следов обтекания ветроустановок и влияние рельефа земной поверхности на формирование профилей скорости ветра за ветроустановками.

Ключевые слова: турбуленция, численное моделирование, энергетические параметры ветра