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CFD Analysis of Water Ring Arising about Floating Rotor of Offshore Wind Power Plant

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ABSTRACT

Paper describes CFD calculations of water flow about floating rotor for new large-scale vertical axis wind turbine supported by pontoon with columns (WEMU type). The research goals are to verify flow mode, to calculate a hydrodynamic power loss, to find out an influence of waves. Water ring arises about the pontoon during rotation. Power loss is proportional to second power of rotational velocity. The ring can drift to outside because of water acceleration and aside due to waves.

KEY WORDS: offshore wind power, CFD, floating rotor, water ring, power loss, waves.

NOMENCLATURE

d: distance from the wall
d_P: diameter of the pontoon's cross-section
D_P: pontoon's diameter
k: turbulence kinetic energy
M_h: total torque of hydrodynamic resistance
M_w: total aerodynamic torque of the turbine
n: number of modules
n_C: number of columns
p: pressure
S_C: cross-section area of a column
S_P: cross-section area of the pontoon beneath sea level
R: radius of the blade circle
(u_1, u_2, u_3): mean absolute velocity
(u'_1, u'_2, u'_3): fluctuating component of absolute velocity
(U_1, U_2, U_3): mean relative velocity
(U'_1, U'_2, U'_3): fluctuating component of the relative velocity
u_{10}: mean wind velocity at 10 m height
(x_1, x_2, x_3): position in stationary coordinate system
(X_1, X_2, X_3): position in coordinate system fixed to rotor
δ_{ij}: Kronecker delta
ε: dissipation rate of turbulence energy
η_h: relative hydrodynamic power loss = M_h / M_w
λ: nondimensional blade speed = $\omega R / u_{10}$
μ: viscosity
μ_t: turbulent viscosity
ρ: fluid density
ω: rotor angular velocity

INTRODUCTION

Offshore wind power plants seem to be the most promising and quickly growing area in wind power engineering. They have obvious advantages over inland power plants. First, they have softer ecological demands, higher blade speed, and therefore, increased efficiency. However, the substantial differences between modern offshore and onshore turbines are located in their support structures only. So, well-known drawbacks of propellers could not be excluded. The limited unit power capacity, infrasound emission, and the harmful effect on birds and animals are noted. Now wind energy cost is higher than that from conventional power plants. In spite of some new projects of offshore horizontal-axis wind turbines having increased power capacity, evidently their capacity has come close to a technological limit. The studies revealed (e.g., Klinger F. et al, 2002) that an efficient 10MW turbine could not be developed within the framework of Dutch design.

Our aims are to increase substantially unit capacity of wind power plants, to work safely under extra wind loads, to enhance wind speed range, to reduce wind energy cost, to eliminate infra sounds and fatal injury of birds due to turbine rotation. The aims can be reached with the recently suggested concept of wind turbines named the Wind Energy Marine Unit (WEMU) (Cheboxarov et al, 2002; Cheboxarov and Cheboxarov, 2002). The WEMU turbine features a large-scale (more than 100 m in diameter) ring floating rotor (see Figs. 1~2). Water supports the rotor during slow rotation about a pile- or isle-based tower.

It has been shown by Cheboxarov et al (2004) that the WEMU turbine has high aerodynamic efficiency despite of a relatively low blade velocity. Its rated aerodynamic power capacity can reach dozens MW. Now key questions of the WEMU design are what a water flow mode about the rotary pontoon is, how large is a hydrodynamic power loss value, how the power loss can be minimized, and how waves influence upon the rotary pontoon. Cheboxarov et al (2002) have discovered the effect of a water ring arising about the rotary pontoon and, after the experimental tests with small pontoons, predicted the hydrodynamic power loss value as less as 6% of aerodynamic power. Linear dependence of the power loss from the pontoon's angular velocity was