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Potential of the Virtual Blade Model in the analysis of wind turbine wakes using wind tunnel blind tests

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Abstract

The present research frontier on wind turbine wake analysis is leading to a massive use of large-eddy simulations to completely solve the flow field surrounding the rotors; on the other hand, there is still room for lower-fidelity models with a more affordable computational cost to be used in extended optimization analyses, e.g. for a park layout definition. In this study, a customized version of the Virtual Blade Model (VBM) for ANSYS® FLUENT® is presented. The model allows a hybrid solution of the flow, in which the surrounding environment is simulated through a conventional RANS approach, while blades are replaced by a body force, calculated by a simplified version of the Blade Element Theory. The potential of the newly-customized VBM was evaluated by applying it to the famous NOWITECH-NORCOWE blind tests for horizontal axis wind turbines. Several test cases were analyzed and discussed including: 1) a single turbine; 2) an array of two turbines with one rotor working in the wake of the other one; 3) an array of two staggered rotors; 4) several configurations of rotors working in yawed-flow. The study proves that the VBM model can represent a valuable tool for the analysis of wind turbines wakes and of their interaction with near rotors.

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Keywords: wind turbine; VBM; wake; wind tunnel; CFD

1. Introduction

The leading role of wind energy in the world scenario is being consolidated in the last few years by all statistics.

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A recent one [1] showed for example that 2015 was an unprecedented year for the wind industry, as annual installations crossed the 60 GW mark for the first time in history, with a cumulative annual market growth of more than 17%. The majority of this power is supplied by large rotors, often clustered into parks. In these installations, the mutual influence of wakes can have a tremendous impact on the turbine efficiency, reaching even 30-40% power losses and fatigue loads up to 80% larger if compared with turbines operating in undisturbed wind [2], with a notable decrease of both the expected revenue of the wind farm and the expected lifetime of the downwind turbines. Since experimental wake analyses of real-scale turbines are extremely expensive and often barely feasible, significant efforts have been made by researchers both in developing mathematical models for the wake description and in extensively using computational fluid dynamics (CFD) [3-4]. The computational cost of these approaches, especially if based on Large Eddy Simulations, is very high and often not compatible with extended optimization analyses typical of the industrial practice (e.g. for a park layout definition). Increasing interest is then devoted at defining simplified techniques for the analysis of wind turbine wakes [5], with particular focus on the far-wake interaction with downstream rotors. If well-known Reynolds-Averaged Navier-Stokes (RANS) CFD approaches represent a valuable trade-off in many applications [6], even more simplified models are being developed in case of multiple rotor analyses, in which a RANS CFD approach is used to solve the flow field everywhere in the domain except on the rotor blades, which are replaced by an equivalent energy extraction from the flow [7]. Upon comparison of these models [8], the authors recently suggested that the adaptation to wind turbines of the Virtual Blade Model (VBM) for ANSYS® FLUENT® may be particularly effective for wake studies. To this end, in the present study the potential of a customized and improved version of the VBM is then evaluated by applying it to the famous NOWITECH-NORCOWE blind tests to assess its potential in correctly reproducing the performance and wake shape of horizontal axis wind turbines in case of both aligned and skewed flow.

Nomenclature

c	local blade chord	[m]
c_D, c_L	drag, lift coefficient	[-]
Cp	power coefficient	[-]
D	turbine diameter	[m]
r, R	local radius, outer turbine radius	[m]
R^2	coefficient of determination	[-]
U	wind speed	[m/s]
y^+	dimensionless wall distance	[-]
Acronyms		
BEM	Blade Element Method	
CFD	Computational Fluid Dynamics	
RANS	Reynolds-Averaged Navier–Stokes	
TSR	Tip-Speed Ratio	
VBM	Virtual Blade Model	
Greek letters		
α	incidence angle	[rad]
γ	yaw angle	[deg]
ρ	fluid density	[kg/m^3]
Ω	turbine revolution speed	[rad/s]
Subscripts		
0	value at infinity	
x, y, z	directions of the reference axes	

2. Numerical techniques

The Virtual Blade Model (VBM) is a user-defined function proposed for the commercial solver ANSYS® FLUENT® (running with a RANS approach). This add-on was originally conceived to model the aerodynamics of propellers and helicopter rotors and it is still used extensively for these purposes, even in military applications [9]. Its application to HAWTs is, however, quite straightforward, even if still not so common (seen only in [7] and [11]).