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Investigation on effect of tower type on downwind turbines

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Abstract:

Due to new materials, control strategies and the fact, that noise is offshore not a driving factor, downwind turbines seem go into a revival. So far Ming Yang, Hitachi and the Dutch developer 2-B Energy have been developing downwind concepts lately [1]. However, the effect of the tower shadow is a crucial question in the aerodynamics for such turbines. One question to be answered is, how good the used blade element momentum (BEM) theory based load calculation models are for such a turbine design. Another question is, how the tower effect could be minimized, since it is regarded as potentially problematic. Here, concerning the first questions, we compare measurement data from a wind tunnel experiment against computational fluid dynamics (CFD) and BEM calculation. In the second part the tower effect of an assumed 5MW turbine following the NREL 5MW turbine [5] concept as a downwind configuration is compared between the standard tower and a lattice tower concept.

In BEM based calculations mostly either a wind deficit, from potential theory, or empirical models are used [1, 2]. Here, we investigate, how much this assumption holds using CFD simulations. We use measurement data from the NREL Phase VI turbine for our research. The mesh generation was done using the bladeBlockMesher, developed by ForWind and Fraunhofer IWES [3]. It creates a structured blockMesh around wind turbines blades. The rotor was meshed separately in a cylindrical mesh from the surrounding mesh. The latter has been meshed in a half-cylindrical way with the hub distance of 5D to the inlet and crossflow cylinder walls and 10D distance to the outflow. Overall ca. 10 Million cells have been used. The k-omega SST model has been used for unsteady RANS turbulence modeling [4]. The results from the BEM code FAST show an approximately 20% higher value for the lift coefficient compared to CFD results. The CFD simulations show a drop of 50% compared to the FAST simulation which has a drop of 70%. For the full scale wind turbine simulation with different tower concepts the towers have been simulated using an actuator line concept for each situation. The blades were in this case considered to be rigid an straight. The layout of the domain was chosen according to the before described simulation. The overall mesh consisted of about 30 million cells. We used a k-omega SST turbulence model for the unsteady RANS simulations. The first results showed a weaker but less localized effect of the lattice tower wake against the monopile tower.

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[5] Jonkman J, Butterfield S, Musial W and Scott G 2009 Definition of a 5-MW reference wind turbine for offshore system development Tech. Rep. February

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Aerodynamic Blade Design Considerations due to Tower Effect on Upwind and Downwind Turbines

Xabier Munduate, Ainara Irisarri and Maria Aparicio

CENER

Abstract:

1. **Introduction:** This work presents the aerodynamic effect that the tower has on the rotor of upwind and downwind configurations and may serve to obtain guidelines for the blade and airfoil design. The rotor configurations studied are:

- The baseline upwind three-bladed 10 MW INNWIND.EU rotor
- The downwind three-bladed 10 MW INNWIND.EU rotor
- A downwind two-bladed design based on the 10 MW INNWIND.EU rotor

2. **Analysis of the configurations:** The results include the comparison of these three cases with and without the tower effect. The analysis focus on the energy production AEP, the rotor power, the tip-speed ratio TSR and the angles of attack. The AEP obtained is higher for the baseline rotor than for the rest of configurations. The reduction of AEP observed is close to 0.12% for the downwind three-bladed configuration, and it is approximately -2.08% for the downwind two-bladed design. The effect of the tower shadow reduces the AEP calculated. This effect presents reductions close to -0.7% for the two-bladed downwind rotor, approximately -0.62% for the three-bladed downwind rotor and even lower for the baseline case (-0.26%). Regarding the rotor power, the tower shadow effect leads to higher frequencies and amplitudes. From 3 to 2 blades (both downwind), the decrease in rotor power is multiplied by a factor of 1.29. TSR has been calculated for the different azimuth positions and it is clear that the standard deviation of the TSR is affected by the configuration. Finally, the angle of attack at 50% span has been analyzed. The variation of angle of attack is low for the baseline case with respect to the downwind configurations, and it is higher for the two-bladed design than for the downwind three-bladed configuration. The range of time where the effect of the tower is evident (Δt) is wider for the upwind case than for downwind cases and it is significant with respect to the period (5.9%-12.3%). The effect in the rate $\Delta AoA/\Delta t$ related to the configuration from upwind to downwind configuration (3 bladed) is very important (4.7 times). While the effect of the change is this variable due to the number of blades is lower (1.29 times).

3. Applications for design

- The tower shadow effect can be only partially taken into account by the blade geometry design.
- The way of considering the tower shadow effect in design could be focused on airfoil design: use airfoils designed to withstand unsteady aerodynamics, airfoils where efficiency does not drop sharply with α variation.

4. Conclusions

- The conclusion is that the tower effect has an impact on both configurations; upwind and downwind.
- As expected, considering the tower, less rotor power is measured with the three configurations studied. The AEP loss is higher for downwind rotors, and higher for 2 bladed rotors.

[Invited Speaker]

The Multi Rotor Solution for Large Scale Offshore Wind Power

Peter Jamieson
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Abstract:

The multi rotor system (MRS) concept involves a multiplicity of small rotors on a single structure as compared to developing ever larger single rotor systems. The idea is not new. Designs of Honnef, for example, in the 1930’s show MRS for onshore and offshore, but the motivation for MRS then lay in the difficulties in making very large single rotors when steel was the main trusted engineering material. Heronemus in the 1970’s advocated MRS noting advantages in standardisation of rotor size. In work on advanced wind turbine concepts for the UK Department of Industry 1995 Jamieson noted an obvious but key advantage of the MRS in much increasing the ratio of system rotor swept area (value in energy capture) to volume (cost in structure and power conversion) compared to an equivalent single rotor.

Present status is reviewed following an international workshop on MRS with presentations of Vestas on their 4 rotor, 900 kW prototype, laboratory and field testing of MRS at Kyushu University, the MOWIAN MRS tested at Kaiser Wilhelm Koog and yaw system design work of HAW Hamburg. A major recent study of MRS for offshore deployment at 20 MW scale was conducted in the Innwind.EU project within the European Wind Initiative (EWI) established under SET-Plan, the Common European Policy for Energy Technologies. Results of this work and implications for future development form the main part of this presentation.

The MRS benefits from standardisation of rotor size with higher production quantities and smaller unit size speeding development, improving reliability and reducing cost. Project investment risk is greatly reduced in employing proven turbine technology at a manageable scale rather than developing ever larger units with longer development times for systems and components and much greater exposure to cost impact of serial faults etc. With benefit from the scaling laws, the weight and cost of the 45 rotors (each rated at 444 kW) and nacelles compromising a 20 MW multi rotor system that has been developed within the Innwind.EU project is ~ 20% of that of a single equivalent rotor and nacelle system. Per installed MW of offshore capacity, about 80% of the glass epoxy composite materials used in blades that are difficult to recycle will be saved.

The design developed within the Innwind project was subject to detailed analyses of aerodynamics, loads, support structure, electrical integration and yawing systems. The total power of n rotors compared to $n \times$ power of a single rotor operating in isolation is found to increase by 8% for the 45 rotor array. The Innwind project compared a number of innovations and results are presented. Levelised cost of energy was evaluated using a cost of energy model adapted from the NREL model and developed independently in another task of Inniwnd.EU. The 20 MW MRS results suggest more than 20% reduction in LCOE based on technology aspects alone without consideration of commercial or industrial factors such as reduced investment risk and standardisation.

Wake Deflection in Long Distance from a Yawed Wind Turbine

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Abstract:

In wind farms where a large amount of wind turbines may lay on several rows, deficits of wind energy to the downstream wind turbines occur, when the downstream turbines operate in the wakes generated by the upstream wind turbines. The aerodynamic interaction between the wind turbines can cause output decrease of the downstream wind turbine. Furthermore, it was confirmed that especially in the condition of wake half-overlapping, severe fluctuation of aerodynamic load occurs on the downstream wind turbine blade. After all, to solve the problems such as the output decrease or increase of fatigue load, avoidance of the wake interference to the downstream wind turbine by operation of wake deflection from the upstream wind turbine is desired. In the present study, firstly, three-dimensional computations of single wind turbine are carried out with changing yaw angles. For the result, focusing on velocity distribution in wake and aerodynamic loads on the yawed wind turbine, we discuss the influence of yaw angle. Secondly, based on the results of the velocity distribution in wake for each yaw angle, we move on to a simulation of avoidance of wake interference to downstream wind turbine, where two wind turbines are prepared. Special CFD solver “rFlow3D” which has been developed in JAXA (Japan Aerospace Exploration Agency) for rotorcraft is used for the computations, because it has capability to handle moving grid systems. RANS (Reynolds-Averaged Navier-Stokes) method with SA (Spalart-Allmaras) turbulence model is used considering its robust nature and short computational time. In the solver, three-level overset grid system is adopted. The first level is the moving grids to resolve the flows around blades, the second is an inner background grid for covering the moving grid and capturing wake field with fine resolution, and the third is a much wider outer background grid which covers the inner background grid for preserving free stream conditions. Through the present study, the following characteristics are confirmed. The operation of wake deflection by adding the yaw angle causes enough wake skew angle even in far-wake. Furthermore, introduction of the yaw angle accelerates progression of vortex dissipation and brings about early velocity recovery in the wake region. Meanwhile, the introduction decreases amount of power generation of the yawed upstream wind turbine and increases fatigue load of flapwise moment added to the blade root. In the final paper, the details of flow field, oscillation and performance characteristics of the yawed wind turbine will be described.

Fundamental Research on Wake Structure of a Simple Vertical-Axis Windmill

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Abstract:

Our final purpose is to propose a new simple and durable windmill and to optimise it. This windmill is composed of a rectangular flat plate rotating about a vertical-axis. The windmill is expected to attain rather low efficiency, however is suitable for small, on-site and self-sufficient systems to generate power in disaster, isolated or remote regions/areas.

The windmill is the application of an autorotation; namely, a kind of self-sustained rotating motion known as ‘tumbling.’ The tumbling is a rotating motion with the axis perpendicular to mainstream’s direction. The tumbling is not only purely-academic concerns found in the falling motions of leaves and pieces of paper, but also a very important phenomenon in such actual aspects as aeronautical and space engineering, ballistics and meteorology in addition to mechanical engineering whose applications are new renewable-energy converters like windmills and waterwheels, smart flow-control devices, mixers/diffusers and so on. So, there have been some researches for the tumbling. However, we have not obtained enough

knowledge about the effect of aspect ratio AR upon the tumbling. This AR effect is important especially for renewable-energy converters from a practical point of view. Moreover, it is necessary to understand the wake structure past a rotating flat plate in order to optimise windmill and waterwheels.

The present study is a fundamental approach on the wake structure of the windmill.More specifically, we conduct a series of subsonic wind-tunnel experiments, in order to investigate the basic aerodynamic characteristics of a tumbling finite flat plate in uniform mainstream. Especially, we focus upon both the effects of an aspect ratio AR and a tip-speed ratio Ω^* which is a reduced form of a rotating rate n upon the tumbling of a finite flat plate, in addition to the Reynolds number Re. We should note that the plate is forced to rotate with a constant speed, because we can easily control Ω^* over a much wider range than freerotation or free-fall experiments. This is suitable as a fundamental approach in the first stage. We carry out

fluctuating-velocity measurements using a hot-wire anemometer together with the synchronized measurements of the plate’s attack angleα which are used for phase-averaging analyses, in addition to flow visualisations. The tested range of a geometrical parameter AR is 0.67 – 5.0. The tested value of Ω^* varies from 0.1 to 3.0. The tested value of Re varies from 3.0×103 – 5.0×104. The tested range of another geometrical parameter λ concerning the plate’s cross section is 2.0×10-2 −

5.0×10-2, which is small enough to be regarded as thin. As a result, we have revealed the effects of AR, Ω^* and Re upon the tumbling of a flat plate. A frequency ratio fd/n as a reduced form of fd is more appropriate to consider flow modes than the flow modes based on the Strouhal number St. The periodicity of fluctuating velocity of a rotating flat plate mainly depends AR and Ω^*, but does not almost depend on Re.