Abstract No.

Exploiting vortex roll-up mechanism to promote wake recovery through a periodic and asymmetric collective pitch motion

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Novel technologies aimed at promoting a faster wake recovery were recently proposed as a possible way to increase the power produced by the whole farm [1]. In fact, in a wind farm, downstream turbines will benefit from an accelerated recovery of the upstream rotor wakes in terms of produced power. Among all possibilities to achieve this goal, this paper focuses on the so-called dynamic induction control (DIC), which consists in a variation of the upstream rotor thrust generated through a suitable blade pitch motion, which, in turn, produces an in-wake mixing responsible for the faster recovery.
Even though this technique proved to be promising in silico and in wind tunnel tests [2], the physical mechanism generating the increased wake velocity is still to be fully understood. Clearly, an improved comprehension of DIC working principles may be exploited for synthesizing different controls able to boost those fluid-mechanics phenomena underlying DIC.
This paper deals with a CFD simulation campaign aimed at analyzing the fluid-mechanics of DIC and exploiting such knowledge to improve its effectiveness. The analyses were carried out with the software SOWFA coupled with OpenFAST [3, 4].
The simulations considered the reference 5MW wind turbine model [5] and an inflow condition with 9 m/s speed and 5% turbulence intensity. Figure 1 shows the two different zero-mean periodic pitch functions, with the same minimum value and period, used for generating DIC. The first (SPCM) is a classical sinusoidal function, while the second (GPCM) is a combination of Gaussian functions, with a significant asymmetry between the negative and positive peaks defined to boost DIC effectiveness.
At present, from the analyses already accomplished, it is possible to derive the following conclusions.
The near wake region is typically shielded from the outer flow by the vortices released at blade tips and re-energization starts in the far wake after such vortices dissipate. With dynamic induction control, the rotor releases vortices of variable magnitude creating regions of higher vorticity around which the shear layer may roll up easily, increasing the exchange of energy with the outer flow. The GPCM strategy boosts such mechanism by anticipating the vortex roll-up, due to an increased difference between high and low vorticity cores, induced by the larger difference between pitch angle peaks.
Figure 2 provides a demonstration for that. The plots represent the vorticity field in a horizontal plane at hub height at the instant of vortex roll-up. Rotor location and downstream distances multiple of diameter D are represented by black thick and thin lines, respectively. Clearly, in the baseline case (a), the vortex that rolls up at 2.5 D is not enough strong and dissolves at 3.5 D breaking into random vorticity. On the other side, in the SPCM case (b), a huge core of high vorticity rolls up at 2.5 D and lasts longer promoting the exchange of energy with outer flow. Finally, in the GPCM case (c), roll-up occurs before, at 1.5 D, yielding a sensible wake recovery already at 2 and 3D.
In the final presentation, the physics of the DIC will be explained in detail along with the quantification of the impact of SPCM and GPCM technique on the total power of a simple two-turbine farm.

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Images:
Link: https://s3-eu-west-1.amazonaws.com/static.vcongress.de/cms/forwind/paper/c0392ffc-2d78-412a-94c8-3c12ec32f923.png
Description: Figure 1: Pitch motion for SPCM (dashed line) and GPCM (solid line)

Link: https://s3-eu-west-1.amazonaws.com/static.vcongress.de/cms/forwind/paper/ca1db24f-8128-498c-8b15-4b0f3bdc9230.png
Description: Figure 2: Vorticity plot in a horizontal plane at hub height at the instant of vortex roll-up

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