Turbulence ahead

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Although the wind may blow smoothly onto a wind turbine, it comes out the other end shredded into a complex collage of whorls, large and small. In a wind farm, the turbulent wake generated by the first row of turbines drives the turbines in the next rows, which produce up to 40% less power and suffer more from bumpier winds. Researchers from EPFL's Wind Engineering and Renewable Energy Laboratory (WIRE) led by Fernando Porté-Agel are developing tools to improve the overall efficiency of wind farms. This July they published their results in two articles in *Boundary-Layer Meteorology*.

"One important factor for designing a wind farm is its layout, or how the turbines are positioned relative to each other," says Yu-Ting Wu, a PhD student at WIRE. In one of the recently published papers, Wu compared results from a numerical simulation of the wind through a wind farm to wind tunnel experiments, focusing specifically on where the turbines are placed within in the wind farm.

Wind farms have often been set up along a square grid. Wu's simulations show that simply changing the wind farm's layout can increase the total efficiency of the wind farm by giving the turbulent wake flow more time to recover before it reaches the next turbine. But finding the perfect setup is far from easy. "You have to remember that layout is relative, and changes with the wind direction," says Wu. For instance, two turbines that are behind each other in southerly winds are next to each other when the wind is blowing from the east.

By the click of a mouse

Having shown that their computer simulation does a good job at replicating measurements made in wind tunnel experiments, Wu and his colleagues can confidently extract data from their numerical experiments that would be difficult to obtain experimentally. It is as if they could equip every point in space with sensors that measure all of the important quantities: wind speed, wind direction, turbulence intensity. But not only that; they can run through any number of scenarios by the click of a mouse, without the painstaking preparation and precision required in wind tunnel experiments.

For his simulations, Wu developed a wind turbine model that captures each turbine's rotation and its interaction with the wind - an improvement over the oversimplified approach commonly used, where the rotors are considered as a porous disc on a pole. Wu's approach is closer to reality. It actually models the rotation of each turbine and the forces generated in the process, providing a more accurate flow field behind each wind turbine.

Wind tunnels with floor-heating

Atmospheric stability is another critical factor influencing a wind farm's power output. For the second article, Porté-Agel and his collaborators at the University of Minnesota set up a series of wind tunnel experiments to study the effects of convection, the rising of warm air common to hot days, on the wake behind a turbine. They mimic the effects of convection by switching on the floor heating in their wind tunnel.

Interestingly, and rather paradoxically, despite the increased turbulence on hot days, the flow behind individual wind turbines recovers faster than in less turbulent nocturnal winds. In other words, on a hot day, a turbine in the second row of a wind farm would not lose as much efficiency as during the night. According to the authors, the stronger turbulence surrounding the turbine wake draws in more forward momentum, which leads to faster recovery of the flow.

As surprisingly as it may seem, wind farms can have an impact on the weather. That is why they have to be included in weather forecast models, in the same way as mountains, forests and cities are today. Finding the most accurate way to include them is another issue Fernando Porté-Agel's work will help to address.

More information: Yu-Ting Wu, Fernando Porté-Agel (2012), Simulation of Turbulent Flow Inside and Above Wind Farms: Model Validation and Layout Effects, *Boundary-Layer Meteorology*.

W. Zhang, C. D. Markfort and F. Porté-Agel (2012), Wind-Turbine Wakes in a Convective Boundary Layer: A Wind-Tunnel Study, *Boundary-Layer Meteorology*.