Analysis and optimization of wind farm performances

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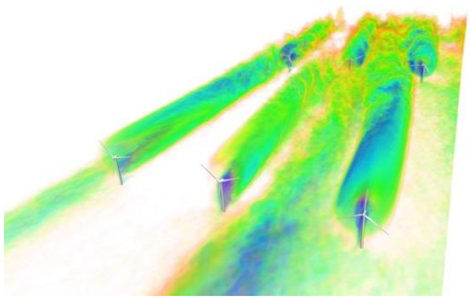

Figure 1 Color contours of instantaneous velocity in a wind farm

Wind energy is a major renewable source for electricity production. Global wind power installed capacity exceeded 740 gigawatts (GW) at the end of 2020. The global penetration of wind energy in electricity markets is estimated at 5% on average; that is 5% of the electricity around the globe comes from wind. However, top electricity markets such as Denmark, Ireland, Portugal, Germany, the U.K. and Spain have penetration levels between 20% and 50%. Italy is the fifth country in terms of cumulative installations in Europe, with 11,320 MW of wind energy installed in 2021 (about 7% penetration), which is expected to reach capacity of 15.21 GW in 2027.

At over 100 GW of installed capacity, wind is the largest source of renewable energy in the U.S. with 7% penetration on the electric grid and six states supplying over 20% of their electricity from wind. The goal in the U.S. is to further increase installed wind capacity to 400 GW and reach 35% of the nation’s electricity generation by 2050.

To increase the production of energy and reduce its cost, the size of the turbines has continuously increased, up to blade lengths of the order of the order of 100 m. This leads to two major challenges: (i) the flow field in a wind turbine array is inherently coupled to unsteady dynamics at the synoptic scale and (ii) the deformation of the blades, and the interaction between the fluid and the structure cannot be neglected. In addition, to increase the penetration of wind energy, turbines are installed in areas of complex topography or near the coastal region. The wind velocity profile and turbulence are site-specific and often the turbines function in off-design conditions. To address these challenges, we developed a numerical model to mimic the behavior of arrays of wind turbines and optimize power production and durability.

At the seminar we will present comparisons of our numerical predictions with measurements in real wind farms and discuss control algorithms that can potentially increase the power production up to 7-10%. We will also describe a procedure to estimate the annual energy production of a wind plant which can be used to evaluate possible upgrades of existing wind farms and mitigate the risk of investment. An initiative to expose undergraduate students to wind energy research will also be presented at the seminar.