Improving wind farm performance through wake research, big data analytics and farm level controls

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In the late 1980's the wind industry grew to MW sized machines and became a supplier of utility scale electricity. Twenty five years later, wind is impacting the electricity supply with more than 487 GW installed, zero emission of greenhouse gas and zero use of water. The impact of turbulence on wind energy has been characterized and modeled by a patchwork of semi-empirical relationships combined with multi-disciplinary background knowledge applied to individual wind turbines in a complex turbulent environment. The development of dedicated aero-elastic modeling including turbulence inflow simulation and dynamic stall models. The approaches used are further guided by the IEC 61400 standards.

Much has changed since then. The Reynolds numbers have more than quadrupled and turbines are operating in complex waked flows in large wind farms, challenging the way we understand the impact of turbulence on the structure and performance. Our fundamental understanding has migrated and additional semi-empirical relations has been added, mostly derived through classical measurements techniques and complementary modeling. However, the full-scale research and validation occurs with very sparse data sets, limited spatial and temporal resolution, partially supported by integral numbers such as rotor power or structural bending movements. Making reliable full-scale measurements for long periods of time is a complex task.

The present knowhow and measurement techniques, such as met-masts and standard LIDARs, are insufficient to deal with both present and future challenges. Emerging methods are promising, but do not capture turbulent scales at high spatial resolution. The hundreds of sensors in each turbine can not only be used for data-mining (big data) the performance in complex wakes, but can also be applied for controls of the wind farms. Future wind farms will be real-time networked and dynamically controlled to optimize the reaction to the incoming wind turbulent flow and manipulate the inter-turbine wake situations. Additionally, we can expect the farms to be equipped with high fidelity (wind) sensors and the blades to include local flow control at high response rates. At present, we can only extrapolate our patchwork to emulate these mechanisms.

New and improved high fidelity measurement techniques combined with data-mining methods, which can properly characterize the turbulence properties and the dynamic response, is needed to generate basic insight for future innovation. Our wind tunnel studies have further supported fundamental findings needed both for data collection and controls. State-of-the-art will be discussed while elaborating upon these future needs.