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Effects of turbulence on wind, lift and power

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Wind turbines operate in fluctuating turbulent atmospheric (atm.) wind fields. While large scale fluctuations are related to fluctuations in power output, small scale fluctuations (in the range of secs) are also related to loads. We focus first on the wind description on small and mesoscales. To do so we investigate the scale dependent statistics of atm. velocity increments (vel. difference over a time τ, $v(t+\tau) - v(t)$) and compare them to that of homogeneous, isotropic and stationary turbulence from laboratory experiments. For these flows the probability density functions (PDFs) show a change in shape (Gaussian on large scales, intermittend on small scales). The atm. PDFs examined here have the markable feature of a shape nearly independent of the scale. This corresponds to the striking feature of intermittent PDF shapes (heavy tailed and not Gaussian) but also a nearly ideal non-multifractal K41 scaling for the structure functions. A key to understanding this feature is to interpret atm. increment statistics as a large scale mixture of subsets of isotropic statistics.The second part of this study focuses on the influence of atm. turbulence on the wind turbine. One effect is the dynamic stall for airfoils caused by fluctuations in wind direction. In contrast to static lift forces there is an overshoot of lift if the angle of attack (AOA) is changed dynamically. The maximum lift, the knowledge of which is relevant for the estimation of extreme loads, depends clearly on the rate of change of the AOA. This effect can be interpreted as an amplifier for large velocity fluctuations in the interaction of wind and airfoil. The fluctuations in the wind and lift forces lead to fluctuations in the electrical power output itself. We show that the rapid fluctuations in wind speed and power output can be used to perform a stochastic analysis of the power output based on a Langevin equation to see how velocity fluctuations affect the power performance characteristics. We can estimate the turbine's power curve from datasets taken over a few days and not, as commonly done, from datasets taken over several months. Finally we see how the fluctuations due to atm. wind turbulence are supplied to the electric power grid.