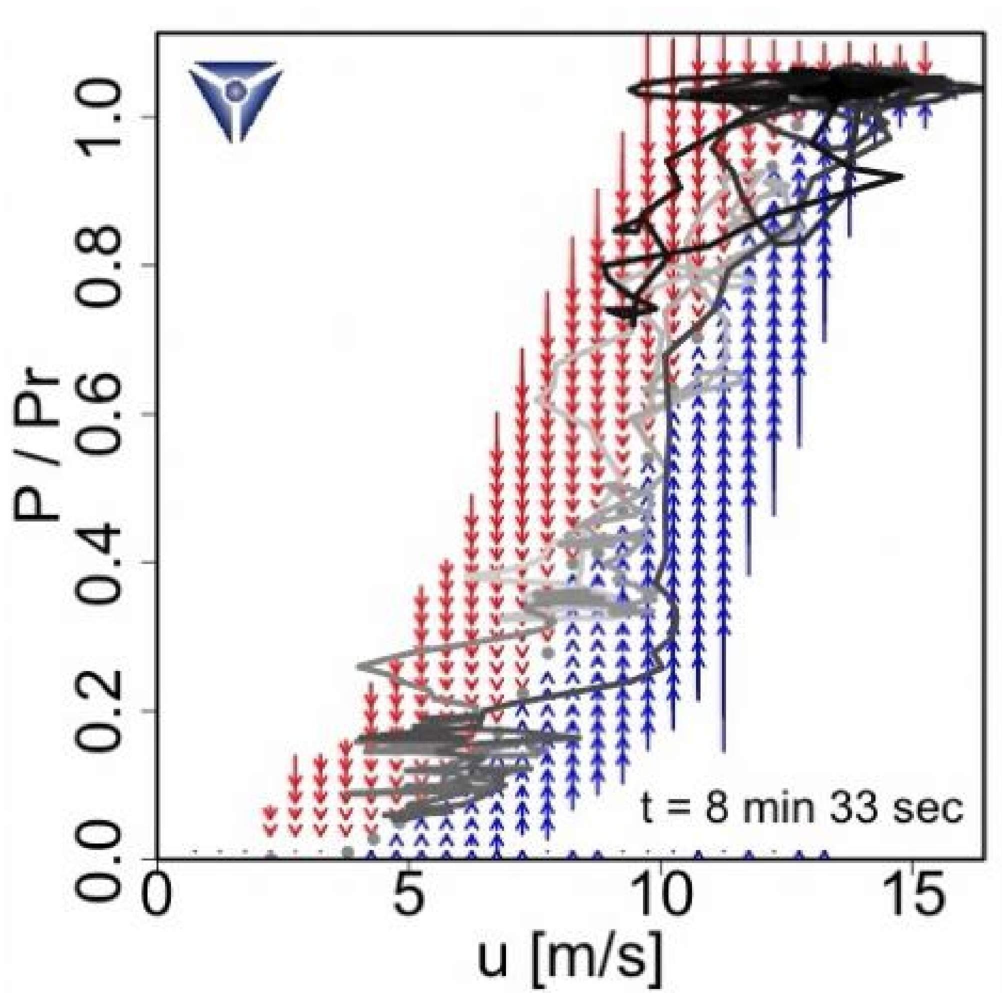
Wind turbines operate under great turbulence, with consequences for grid stability

April 19 2013, by Lisa Zyga



Screenshot of a movie (see below) showing the power output vs. wind speed signals for a wind turbine. Credit: Patrick Milan, et al. ©2013 American Physical Society

(Phys.org) —While previous research has shown that wind turbulence causes the power output of wind turbines to be intermittent, a new study has found that wind turbulence may have an even greater impact on power output than previously thought. The researchers modeled the conversion of wind speed to power output using data from a rural wind farm. The results showed that the intermittent properties of wind persist on the scale of an entire wind farm, and that wind turbines do not only transfer wind intermittency to the grid, but also increase it. The findings highlight the importance of fully understanding the physics of wind turbulence in order to ensure future grid stability.

The researchers, Patrick Milan, Matthias Wachter, and Joachim Peinke, at the ForWind—Center for Wind Energy Research at the University of Oldenburg in Germany, have published their study "Turbulent Character of Wind Energy" in a recent issue of *Physical Review Letters*.

In their paper, the researchers address the challenges that large-scale wind energy production may bring to future power grids. They explain that today's grids are powered mainly by a few large generators with controllable input (mostly gas, coal, hydraulic, and nuclear power plants). Power generation from these sources can be modified automatically in order to balance power generation and consumption, and thus ensure grid stability. But while today's power sources are largely controllable, wind power is uncontrollable and highly intermittent.

For time scales larger than several minutes, the conversion of wind speed into electrical power can be modeled by a standard average power curve. But at smaller time scales, the researchers found that the conversion process diverges from this curve. Instead, short-scale conversion follows a more complex pattern involving multifractal scaling that is reminiscent of a 1962 theory of turbulence developed by mathematician Andrey Kolmogorov.

"Looking at an operating wind turbine, one may get the impression that the turbine turns smoothly, but looking at the power output, which is the consequence of the forces and torques inside the machinery, we see that the fluctuations are very turbulent," Peinke told *Phys.org*. "Changes of MW (more than one thousand horsepower) in seconds become obvious. Thus one may compare a wind turbine with an airplane in the landing phase during a very windy situation. From outside, the airplane may look it's going quite smoothly, but inside there is another impression caused by turbulent dynamics. One should also note that a wind turbine has to operate permanently in this 'turbulent landing' condition."

The model also reveals that moderately intermittent wind power is converted to highly intermittent power output. In other words, wind turbines do not only transfer wind intermittency to the grid, but they also amplify it. For instance, the researchers observed that changes in wind speed of about 11 m/s within 8 seconds may cause nearby wind turbines to change their power output by about 80%. The researchers attribute this amplification to the nonlinear conversion process and fast reaction time of the output to changes in wind speed.

"The features of small-scale turbulence are mapped by the wind turbines directly into the electric grid," Peinke said. "As turbulence and in particular the statistics of small-scale wind fluctuations are still considered to be an unresolved problem, this lack of knowledge may become important in the power grids, especially if such power grid are dominated by wind power. As these phenomena take place in the range of seconds, the dynamics of the power grid in these time scales have to be investigated in detail. One has clearly to state that the first step to solve a problem is to be aware of it and to understand it."

The data also shows that wind power intermittency does not only affect the output of individual turbines, as previous research has shown, but it also extends to entire wind farms, which has not been observed before.

The researchers explain that wind farm intermittency is somewhat counterintuitive, since it might be expected that summing the output of wind turbines will average out their turbulent fluctuations. However, wind farm intermittency may be explained by long-range correlations observed in winds. While the wind farm the scientists observed covered an area of about 4 km^2, wind correlations have previously been observed to extend to lengths of hundreds of kilometers. Based on these observations, the researchers expect that wind farm intermittency effects may persist up to these large scales.

Overall, the physicists conclude that their results stress the importance of accounting for the intermittent and multifractal nature of wind power when designing components for wind power, including energy storage technologies. They note that the situation is similar to the findings from many years ago of the intermittent and multifractal nature of the stock market. In both areas, frequent occurrences of fluctuations must be understood and accounted for in order to maintain stability and avoid widespread disruption.

In the future, the researchers plan to further investigate the consequence of wind turbulence on grid stability and develop methods to minimize the negative effects. New turbulence models may help lead to new concepts that reduce the power and load fluctuations on the grid.

"For all of these topics, a deep and comprehensive understanding of the complexity of turbulence is indispensable," Peinke said.

More information: Patrick Milan, et al. "Turbulent Character of Wind Energy." *PRL* 110, 138701 (2013). DOI: 10.1103/PhysRevLett.110.138701