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Review Article

Boundary-layer anemometry by optical remote sensing for wind energy applications

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Abstract

The effective use of wind energy requires precise wind speed measurements. However, there is a risk that existing in-situ techniques with cup anemometers mounted on masts will exceed mechanical and financial limits at future hub heights. Ground-based optical remote sensing methods that measure the vertical profile of wind speed up to several hundred metres height may be a solution to these problems. This review paper will discuss the basic principles of anemometry by remote sensing and will present some optical methods in more detail.

Zusammenfassung

Die effiziente Erzeugung von Windenergie benötigt präzise Windmessungen. Die zur Zeit gebräuchliche Messtechnik mit Schalenkreuzanemometern wird jedoch bei zukünftigen Nabenhöhen an mechanische und finanzielle Grenzen stoßen. Bodengestützte optische Fernmessverfahren, die das Windprofil bis in einige hundert Meter Höhe messen, könnten eine Lösung für diese Probleme sein. Dieser Übersichtsartikel diskutiert die Grundprinzipien der Fernmessung des Windprofils und stellt einige optische Verfahren genauer vor.

1 Problems

Wind-energy applications require accurate measurement of wind speed and turbulence. The location of wind-energy sites ("wind farms") as well as the siting of individual turbines depends on accurate measurements, because of the strong dependence of available energy on wind speed, i.e., the power derived from the wind is proportional to the cube of its speed. During operations optimum turbine performance may also depend on adjusting rotor settings to accommodate temporal changes in the nonstationary wind direction or speed that may occur, especially in the night-time stable boundary layer. As another more extreme example, certain frequencies of atmospheric turbulence can be in resonance with the fundamental frequencies of the rotor blades, causing the blades to "ring." Although such turbulence episodes occur only rarely, they can cause significant damage to hardware components of the turbines (KELLEY et al., 2005). Detection of such turbulence bursts in real time could be of great advantage to turbine operation. Also potentially harmful to wind energy converters are strong vertical gradients of wind speed and turbulence, which can occur under certain meteorological conditions (e.g. inversions or low-level jets). Current turbine technology generally employs blades with diameters of 60 to 110 m attached to their hub at heights of 70 to 100 m. Because wind speed generally increases with height in the layer occupied by turbines, future turbines are being designed to be larger and reach higher, with diameters extending to 125 m, and hub heights to 120 m. The requirement for accurate wind-speed measurements thus extends above the surface to $\sim$200 m. Operationally, data availability at intervals of minutes is needed to monitor changes in wind speed in nonstationary nocturnal flows, but detection of potentially harmful turbulence would require measurements to be available in real time at intervals of seconds. Wind measurements for wind energy purposes have been performed so far mainly with cup anemometers. After diligent calibration based on producing correct turbulence intensities, these devices deliver precise wind data (KRISTENSEN, 1999). However, due to the size of the anemometer, these measurements are representative of a quite small air volume only. The cross-section perpendicular to the mean wind direction is about six orders of magnitude smaller than the rotor area of today's wind turbines. Additionally, the wind direction can not be measured by cup anemometers. A further disadvantage of in-situ techniques is the necessity of erecting tall towers or masts (at least up to the

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