research area
wind and turbulence

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today >5MW - from all ok

area = 12469 m²
power output - conversion dynamics
dynamics of power conversion

\[ P_{WT} = \frac{1}{2} c_p(\lambda) \rho u_{wind}^3 \cdot A \]
time series of power production
energy resource wind

resource is highly turbulent

from meteorological scales
to micro scales

What is the standard characterization
wind measurements and data analysis

.characterization after IEC norm
Statistics of gusts

Wind fluctuations can be measured by velocity increments

\[ u_\tau = u(t + \tau) - u(t) \]
statistics of gusts

\[ \tau = 4 \text{ s} \]

\[ P(u_\tau > 6\sigma) \approx 10^{-4} \]

\[ P rob(u_\tau > 6\sigma) \approx 10^{-10} \]

\[ \frac{1}{1/3000 \text{ Jahre}} \]

\[ \frac{1}{1/Tag} \]

IEC ↔ statistical analysis

ForWind
Center for Wind Energy Research
IEC Wind and measured

IEC Code

\[
\frac{f S_k(f)}{\sigma_k^2} = \frac{4f L_k/U_h}{(1 + 6f L_k/U_h)^{5/3}}
\]

Observation

EUROMECH 528, S. Basu Uni Texas, Austint
incident wind field
EXISTENCE AND SMOOTHNESS OF THE NAVIER–STOKES EQUATION

CHARLES L. FEFFERMAN

The Navier–Stokes equations are then given by

\[ \begin{align*}
(1) & \quad \frac{\partial}{\partial t} u_i + \sum_{j=1}^{n} u_j \frac{\partial u_i}{\partial x_j} = \nu \Delta u_i - \frac{\partial p}{\partial x_i} + f_i(x, t) \quad (x \in \mathbb{R}^n, t \geq 0), \\
(2) & \quad \text{div } u = \sum_{i=1}^{n} \frac{\partial u_i}{\partial x_i} = 0 \quad (x \in \mathbb{R}^n, t \geq 0) \\
(11) & \quad p, u \in C^\infty(\mathbb{R}^n \times [0, \infty)).
\end{align*} \]

A fundamental problem in analysis is to decide whether such smooth, physically reasonable solutions exist for the Navier–Stokes equations. To give reasonable leeway to solvers while retaining the heart of the problem, we ask for a proof of one of the following four statements.
research topics

wind and turbulence are the working conditions for a wind turbine

- 100 km weather
  - forecasting for grid integration
- 10 km orographic effects
  - local working conditions, power production
  - wind frame
- 1 km extreme events, thunderstorm;
  - loads and grid problems
  - low level jets, wakes
- 100 m inflow conditions
  - conversion dynamics, loads on rotor, drive train
  - gusts
- 1 m aerodynamic conditions
  - lift and drag forces, stall, high frequency strokes
- 1 mm flow detachment at profile

- turbulence is full of structures on all different scales
  - extreme events on all scales - nonlinear chaotic and hard to predict
  - seem to come from nowhere and vanish suddenly
Smooth turning turbines from outside.

Innovation by better understanding the energy resource - basic research on wind and turbulence necessary.