Characterization of Wind Power Fluctuations and Prediction

RAVE-Project: Grid Integration of Offshore Wind Farms

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Outline

- Motivation
- Test Case: Cold Surge over the North Sea
- Metric to quantify wind power fluctuations
- Dependence on wind speed and thermal stability
- Summary and Outlook
Motivation:

- Known wind power fluctuations at Horns Rev
- Very strong wind speed fluctuations are observed at FINO1 in 5min averages from 1Hz cup anemometer (equivalent to spatial smoothing at Alpha Ventus)

Key Problem:
wind fluctuations occur due to sub-grid processes that are not explicitly modelled yet (in NWP).

Operational NWP models have hourly time resolution (or coarser)

link with large-scale variables (e.g. stability)
Influence of Thermal Stability on Wake Effects

AV05-power curve 06-12.2011 - FINO1 255-205° - P>250kW Shear $\frac{FF_{90}}{FF_{40}}$

Shear SH

N= 18631

- $SH < 1.03$ N= 21.7 %
- $1.03 < SH < 1.1$ N= 56.3 %
- $SH > 1.1$ N= 21.9 %

rel. Power [t]

rel. Wind Speed FINO190 [1]
Influence of Turbulence on Wake Effects

AV05 - power curve 06-12.2011 - FINO1 255-285° - P>250kW

\[ T_I = \frac{\sigma_{\text{ref}}}{\text{FF}_{\text{90}}} \]

Turbulence Intensity $T_I$  
- $T_I > 4.5\%$  
- $3\% < T_I < 4.5\%$  
- $T_I < 3\%$  

$N = 20648$, $N = 27.4\%$, $N = 34.6\%$, $N = 38\%$
Test Case: Cold surge (4 June 2009)

Synoptic Situation at 4 June 2009, 0UTC

850hPa Temp at 3 June, 0UTC

30h later: 850hPa Temp at 4 June, 6UTC

Stability [K/km]
Test case: Cold surge (4 June 2009)

Fluctuation (FiNO1) at 3 June, 0UTC

30h later: 4 June, 6UTC

\[ \Gamma = \frac{\Theta_v^{925} - \Theta_v^{SKT}}{dz} \]

Speed [m/s]

Stability [K/km]
Test case: Cold surge (4 June 2009)

- Downscaling Experiment: Wind field at 100m with COSMO (dx=1.6km)

3 June 2009, 0UTC

30h later: 4 June 2009, 6UTC

COSMO simulates very heterogeneous wind field in unstable thermal stratification

Test case: Cold surge (4 June 2009)

- Downscaling Experiment: COSMO, dx=1.6km

Vertical wind speed 4 June 2009, 6UTC  Horizontal wind, 100m

COSMO simulates very heterogeneous wind field in unstable thermal stratification

NWP Resolution matters!

Analysis @ 4 June, 6UTC

Operational: COSMO-DE (2.8km)

Downscaling: 1.6km @ 4 June, 6UTC

COSMO-EU (7km): +6h Forecast @ 4 June, 6UTC
Open cellular convection at June 4, 2009 6UTC

COSMO downscaling (1.6km) low cloud cover (%)

Source: Meteosat 9 Vis Dundee Receiving Station
Wind Power Fluctuations at FINO1 (13 Oct 2009)

- Metric: Sum of gradients within a certain time period
- Optional: only gradients that exceed a certain threshold

\[ \text{totalfluc} = \sum_{i}^{6h} |P_i - P_{i-1}| \]

For this study:
- Time period: 6h
- Gradient Threshold: 20%

Example 1:
\[ \text{Totalfluc}_{0.0,0.2} = 4.53 \]

Example 2: \[ \text{Totalfluc}_{0.2,1.0} = 5.41 \]
Strong fluctuations (>20% of installed power) occur predominantly in autumn
Alternative (but complicated) approach HHT: Hilbert-Huang-Transform

wind speed time series
Comparison HHT and totalfluc

Wind speed gradient (5min)

[Graph showing wind speed gradient over 29 days in March 2006]

totalfluc, total amplitude of HHT

[Graph showing total amplitude over 29 days in March 2006]
Comparison HHT and totalfluc (one year, 6hourly)
All $\text{Totalfluc}_{0-1}$ depending on thermal stability and wind speed

- Thermal stability $\Rightarrow$ gradient of pot.virt Temp $=$ \( \Theta_{925} - \Theta_{\text{surface}} \)/dz,
  here: from ECMWF analysis
- 10m wind speed forecast (intraday)
- 4 years (2006-2009)

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**Diagram:**
- Low fluctuation
- High fluctuation
- No fluctuations at all (nominal power)
Strong Totalfluc$_{0.2-1}$ depending on thermal stability & wind speed

- Thermal stability (=gradient of pot.virt Temp=$(\Theta_{925} - \Theta_{surface})/dz$, here: from ECMWF analysis)
- 10m wind speed forecast (intraday)

False alarms on fluctuations with high gradients can not be avoided!
Summary and Outlook

- Sum of relevant gradients (totalfluc) is a simple metric for wind power fluctuations and is related to i) Wind speed and ii) atmospheric stability

- Atmospheric conditions (large scale synoptic situation (cold surge)) leading to fluctuations can be forecasted by NWP

- Mesoscale model COSMO simulates heterogeneous wind field in unstable thermal stratification (but resolution matters)

- Evaluate totalfluc with measured wind power and establish relation to more large-scale forecast variables (cyclonicity) or small-scale variables (TKE, vertical wind speed)

- Use heterogeneous fields from mesoscale modelling to define a „spatial“ fluctuation metric and link with „temporal“ totalfluc

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