(Large Scale) Meandering in Wind Farms

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(Large Scale) Meandering in Wind Farms.

S J Andersen, J N Sørensen, R F Mikkelsen

November 13, 2015
Overview

1. Motivation
2. Methodology
3. Simulations
4. Results - Flow Characteristics
5. Results - Power Production
6. Results - Loads
7. Conclusions and Discussion
Motivation

1 Motivation

2 Methodology

3 Simulations

4 Results - Flow Characteristics

5 Results - Power Production

6 Results - Loads

7 Conclusions and Discussion
As the size of wind farms continue to grow, there is an increasing demand for understanding and predicting wake effects. The importance of wake effects are basically related to:

- Decreased production
- Increased loads.
Meandering or low frequency undulations have been attributed to arise from several different phenomena:

- Atmospheric turbulence (Larsen et al., DWM).
- Instability of the hub vortex (Iungo et al., 2013).
- Rotating helical vortex core (Okulov et al., 2014).
- Strouhal (Medici et al., 2006).
- Turbine spacing (Andersen et al., 2012).

This work presents preliminary results of LES of very large wind farms aimed at elucidating on meandering and its effects in very large wind farms.
Methodology

1 Motivation

2 Methodology

3 Simulations

4 Results - Flow Characteristics

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7 Conclusions and Discussion
Modelling a Wind Turbine and its Wake

Fully coupled LES and aero-elastic codes.
NM80 Turbine

- NM80.
- $R = 40m$.
- $U_{\text{rated}} = 14m/s$.
- $P_{\text{rated}} = 2.75MW$.
- Variable speed P-controller and PI-pitch angle controller.
Turbine Controller

- $U_{\text{hub}}$ vs. RPM
- $C_T$ vs. $U_{\text{hub}}$
- $P_{\text{AW}}$ vs. $U_{\text{hub}}$
- $RPM_{\text{max}}$ vs. $U_{\text{hub}}$
Simulations

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Simulations

60 mins of real time, 10 min averages shifted by 1 min (not statistically independent)

Table: Overview of simulations.

<table>
<thead>
<tr>
<th>Name</th>
<th>$U_0$</th>
<th>TI</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>s12u8ti0</td>
<td>8 m/s</td>
<td>0%</td>
<td>$12R \times 20R$</td>
</tr>
<tr>
<td>s12u8ti3</td>
<td>8 m/s</td>
<td>3%</td>
<td>$12R \times 20R$</td>
</tr>
<tr>
<td>s12u8ti15</td>
<td>8 m/s</td>
<td>15%</td>
<td>$12R \times 20R$</td>
</tr>
<tr>
<td>s12u15ti15</td>
<td>15 m/s</td>
<td>15%</td>
<td>$12R \times 20R$</td>
</tr>
<tr>
<td>s20u8ti15</td>
<td>8 m/s</td>
<td>15%</td>
<td>$20R \times 20R$</td>
</tr>
</tbody>
</table>
Inflow Conditions:

Simulations

Shear exponent: $\alpha_{PBL} = 0.14$.
Inflow Conditions:

Same Mann turbulence applied with different forcing. Streamwise velocity 1R upstream 1st turbine.
Results - Flow Characteristics

1 Motivation
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Box Plots explained

- Compact way to show distribution of data.
- Box made up of first, second (median), and third quartile.
- Maximum and minimum extend would correspond to 99.3% coverage for normally distributed data.
- Outliers excluded in this context.

http://informationandvisualization.de/blog/box-plot
Velocity distributions:

Instantaneous (1 Hz)

Turbine No.

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Directional Variability:

Inflow to 1st and 4th turbine

![Graph showing directional variability of inflow to 1st and 4th turbine.](image-url)
Directional Variability:

Inflow to 11th and 12th turbine

[Graph showing directional variability for inflow to 11th and 12th turbine]
Results

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Power productions:

![Graph showing power production over time for different turbines.](image-url)
Correlation between different turbines:

$TI = 0\%$

$TI = 3\%$

$TI = 15\%$
Results

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Yaw moments:

- Instantaneous (1 Hz)

- 10 mins
Correlation between simulations:

- Power
- Yaw moment
- Tilting moment

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Conclusions and Discussion

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Conclusions and Discussion

- Converged velocity after about 4th turbine.
- Time and directional variability of LES comparable with measurements?
- Increased correlation further into the farm indicates self-organised motion.
- Atmospheric turbulence seems to assist/increase the self-organised motion.
- Self-organised motion or large scales are inherent, but dependent on spacing and/or $C_T$.
- DWM assumption is questionable further into the farm.
- Certain turbines produce significantly more, but also experience higher loads, irrespective of turbulence intensity.
Acknowledgements

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Thanks for your attention.