Numerical CFD comparison of Lillgrund employing RANS

EERA DeepWind 2014
Deep sea offshore wind power
22-24 January 2014
Trondheim

Nikolaos Simisiroglou\textsuperscript{a,b}, Simon-Philippe Breton\textsuperscript{b}, Giorgio Crasto\textsuperscript{a}, Kurt Schaldemose Hansen\textsuperscript{c}, Stefan Ivanell\textsuperscript{b}

\textsuperscript{a} WindSim AS, Fjordgaten 15, N-3125 Tønsberg, Norway
\textsuperscript{b} Uppsala University, Campus Gotland, Visby SE 621 67, Sweden
\textsuperscript{c} Technical University of Denmark, Nils Koppels Alle 403, Kgs. Lyngby DK 2800, Denmark
Content

• Industrial PhD
  • WindSim AS
  • Uppsala University

• The Actuator Disc Concept

• Lillgrund
  • Lillgrund 120 Row 5 & Row 3
  • Lillrgrund 222 Row D & Row B

• Summary

• Future Study

• Acknowledgments
WindSim AS

- Established in 1993
- WindSim - World class software launched in 2003
- Ownership - Privately held company and venture backed
- Business areas
  - Software solutions, consulting services and training
    - Wind farm simulation and wind energy assessment
    - Entire wind farm lifecycle (pre/post construction)
    - Onshore and offshore
- WindSim AS has offices and reseller partners in: Argentina, Brazil, China (2), Costa Rica, Greece, Italy, India, Iran, Korea, Mexico, Norway, Serbia, Spain (2), Turkey, and USA

WindSim offices and resellers

WindSim HQ in Tønsberg, Norway

www.windsim.com

DeepWind 2014 – Deep sea offshore wind power, Trondheim
Uppsala University Campus Gotland Wind Energy

Research

- From research on wake instabilities to simulations of complete wind farms
- Behavior of wakes and wake-turbine interactions
- Applied research on farm optimization
- Numerical Methods Actuator
  - Actuator Disk (ACD)
  - Actuator Line (ACL)

Education

- 1 Year Master program on campus in: Wind Power Project Management
- 11 Distance courses in Wind Power

~ 15 Senior researchers
7 PhD students

Nordic Consortium: Optimization and Control of Wind Farms

DeepWind 2014 – Deep sea offshore wind power, Trondheim
Actuator Disc Concept

The thrust, momentum sink for the axial flow, is supposed evenly distributed on the swept area (uniform pressure drop)

By definition axial induction factor

$$a_i = \frac{u_{\infty i} - u_{1i}}{u_{\infty i}}$$  \hspace{1cm} (1)

Betz’s theory

$$a_i = \frac{1}{2} \left(1 - \sqrt{1 - C_{T,i}}\right)$$  \hspace{1cm} (2)

Uniform:

$$t = \frac{T}{A} = C_T \frac{1}{2} \rho u_{\infty}^2$$

Polynomial:

$$t(r) = C_1 + C_2 r^2 + C_3 r^4$$
Lillgrund Offshore Wind Farm

- Located in Øresund consisting of 48 wind turbines (Siemens SWT-2.3-93)
- The presence of shallow waters caused the layout of the wind farm to have regular array with missing turbines (recovery holes).
- Very close inter-row spacing (3.3xD and 4.3xD)

- The maximum peak loss occurs for the second turbine in the row and is, for inter row spacing of 4.4xD, typically 70%, and for row spacing of 3.3xD, typically 80%.(Dahlberg, 2009)
- The turbine production efficiency rate for the entire wind farm has been found to be 67% if only below rated wind speeds are considered. (Dahlberg, 2009)
Different Parameters Analysed

- Grid sensitivity study
  - D/6 (approximately 15.3 m)
  - D/8 (approximately 11.5 m)
- Main Inflow angles
  - 120 degrees, TI=7.8
  - 222 degrees, TI=5.6
  - 300 degrees, TI=6.0
- Axial thrust distributions
  - Uniform
  - Polynomial
- Turbulence closure models
  - Standard k-epsilon,
  - Modified k-epsilon
  - K-epsilon with YAP correction
  - RNG k-epsilon
Lillgrund  Row 5  120 ± 2,5 degrees

Lillgrund 120 Degrees Direction Row 5

120 Degrees Direction Row 5

Turbine data
D/6th Polynomial KE YAP
D/8th Polynomial KE YAP

Normalized Power

Turbine A-05 to G-05 going from left to right

Lillgrund 120 Degrees Direction  Row 5

DeepWind 2014 – Deep sea offshore wind power, Trondheim
Lillgrund  Row 3  120 ± 2,5 degrees

Turbine A-03 to H-03 going from left to right

Lillgrund 120 Degrees Direction Row 3

Turbine Data
RNG KE Polynomial
KE YAP Polynomial
Modified KE Polynomial
Standard KE Polynomial

DeepWind 2014 – Deep sea offshore wind power, Trondheim
Lillgrund Row D 222 ± 2.5 degrees

Lillgrund 222 Degrees Direction Row D

- Turbine Data
- RNG KE Polynomial
- KE YAP Polynomial
- Modified KE Polynomial
- Standard KE Polynomial

Normalized Power

Turbine D-08 to D-01 from left to right

Lillgrund 222 Degrees Direction Row D
Summary

• Estimation capture the power production from wakes within the error bars of the experimental data.

• The results achieved using the higher resolution, D/8, outperform those obtained using the lower resolution simulation D/6.

• The polynomial distribution, by representing more accurately the thrust force distribution on the rotor, leads to results of higher accuracy in comparison to the uniform distribution.

• Good performance standard k-epsilon, modified k-epsilon and k-epsilon with YAP correction overestimate the power output of the second wind turbine in the row.

• RNG k-epsilon captures in some cases the power production reduction in the second wind turbine but underestimates the following wind turbines of the row.
Future research

- Include additional analysis of the total amount of simulated result in further search for general trends.

- Moreover research will be directed on how to include meandering and swirl effects in the wake model used in this analysis.

- Finally studies with higher grid resolution will be conducted and comparison with analytical models and LES models will be conducted.
Acknowledgements

This research has been supported by:

The Research Council of Norway

Vattenfall Vindkraft