Experimental Investigations of Wind Turbine Wake Towards Offshore Wind Farm Performance Validation

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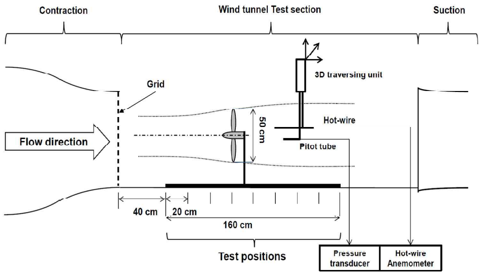
Motivation

- Laboratory scale representation of atmospheric turbulence and wake generated by Wind Farm
- Near wake investigation exposed to different turbulence contents
- Validation of the offshore wind-farm model performance based on experimental results
- Observation of fluid flow phenomena inside Wind farm due to wake generated turbulence

Approach

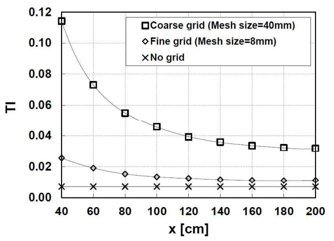
Experimental Setup

- Tests are conducted in the closed loop wind-tunnel of LSTM, FAU Erlangen
- The wind turbine is exposed to turbulent flow of different scale
- Turbulence and velocity profile of wind flow are measured by Hot-wire and Pitot-tube, respectively

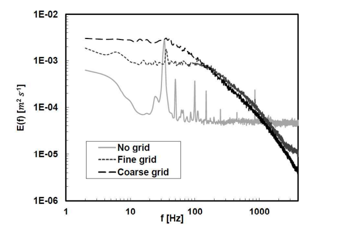


Grid Generated Turbulence

- The turbulence level increases with the installation of the fine grid at the entrance of the test section
- The same effect, but in a higher level of turbulent intensity, is depicted when using of the coarse grid
- The turbulence scale decays in the flow direction

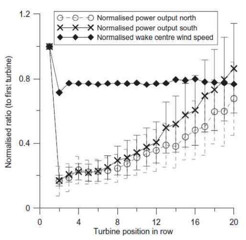


averaged oncoming wind speed of 8-16 m/s
Turbulence Intensity along the wind-tunnel test section

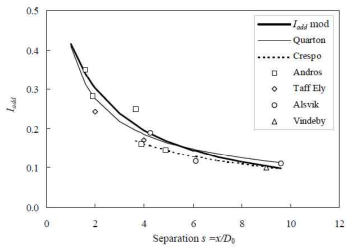


Energy Spectrum E(f) versus eddies frequencies f
at the design free-stream wind velocity 12m/s, TI=0.039
hot-wire position at x=120cm with the absence of wind turbine

Offshore Wind Farm Data and Model



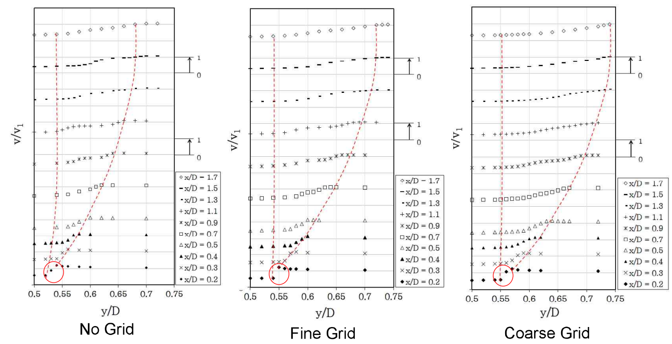
Power & Velocity output under wake
Inside Middelgrundel Offshore Wind Farm [1]



Added Turbulence Intensity versus turbine position
By different model and wind farm measurements [2]

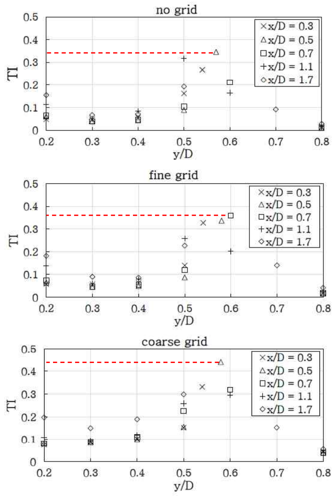
Result & Discussion

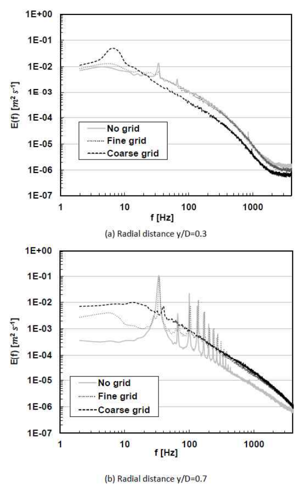
Axial Velocity distribution of near wake



Downwind velocity distribution normalized by the design oncoming wind velocity of v1=12 m/s
x/D is the axial downwind distance normalized by the wind turbine diameter
y/D is the radial distance normalized by the wind turbine diameter

Turbulence Intensity and Energy Spectrum





- Axial Velocity Profile shows tip-vortex, mixing and velocity restoration
- The highest turbulent intensity is observed at x/D=0.5 or 0.7 at near wake
- Wake mixing and Tip Vortex Phenomena are shown by analyzing the spectra E(f)
- E(f) distributions show suppression of tip vortex at higher turbulence
- Flow characteristics are different according to blade radial position

[1] Modelling and Measurements of Power Losses and Turbulence Intensity in Wind Turbine Wakes at Middelgrunden Offshore Wind Farm, R. J. Barthelmie, etc, Wind Energ. 2007; Wiley Inter science, DOI: 10.1002/we.238 [2] Turbulence and turbulence generated structural loading in wind turbine clusters, Sten Tronæs Frandsen, Risø National Laboratory, Roskilde, Denmark, January 2007

Conclusion

- TI from 0.07 to 0.114 and E(f) distribution of generated turbulent flow to mimic offshore wind farm atmosphere are generated in laboratory scale
- High turbulence content of oncoming wind increased wake-surrounding interaction with more energy entrainment to the wake regime as higher turbulence can penetrate through turbine rotor plane
- Higher turbulent flow brings different scales and hence more mixing in the near-wake regime with causing faster wake recovery
- Wake recovery part of axial velocity profiles were in same context of TI described by offshore wind farm models
- Experimental results describe TI distribution, tip vortex and flow mixing at near wake (up to x=1.7D)

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