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Aero-elastic study with turbulent wind and wake effect: comparison between large-eddy simulation (LES) and classical statistical method conform to standards

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Abstract

Design studies use today statistical wind models with turbulence intensity computed from Frandsen (2007) .

In this work we compare the statistical wind generator TurbSim with the OpenFOAM based model SOWFA (both developed by the National Renewable Energy Laboratory, Churchfield et al. 2012). SOWFA couples directly instantaneous wind, obtained by a LES, with an aero-elastic tool .

Two turbines (NREL 5 MW) were placed in the simulation domain. The wake effect from the first turbine on the second one was investigated.

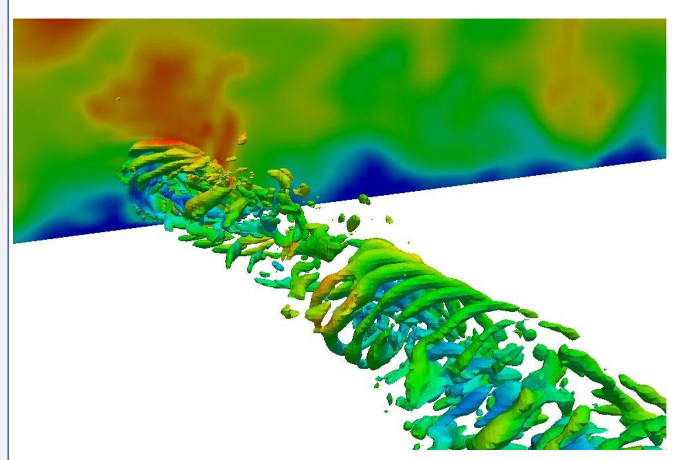
Methodology

FAST

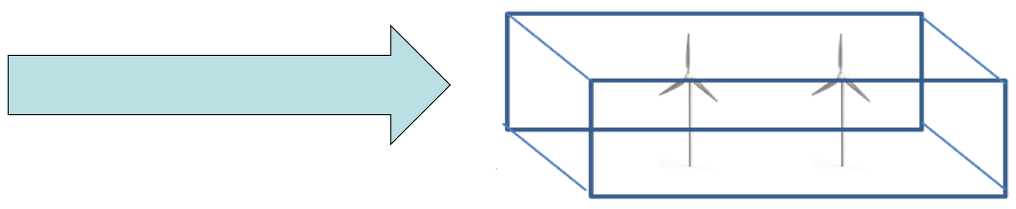
- aero-elastic simulator able to predict extreme and fatigue loads
- multi-body approach
- blade element theory

SOWFA

- turbulent wind flow provided by large-eddy simulation (OpenFOAM)
- wake effect simulated by actuator line model
- directly coupled with FAST (2-way coupled)
- high CPU cost



Wake effect between turbines simulated by actuator line model



TurbSim

- generation of turbulent wind from theoretical spectrum
- input necessary for turbulence intensity
- very low CPU cost

$$S_k(f) = \frac{4\sigma_k^2 \frac{L_k}{U_{hub}}}{\left(1+6f\frac{L_k}{U_{hub}}\right)^{\frac{5}{3}}}$$

Kaimal spectrum depends on mean velocity and standard deviation that is function of the turbulence intensity

WAKE EFFECT (2nd turbine) COMPARISON between

- **SOWFA (FAST+OpenFOAM)**
- **FAST + TurbSim forced** (mean velocity and turbulence intensity from SOWFA)
- **FAST + TurbSim IEC** (mean velocity and turbulence intensity from IEC standard)

Results

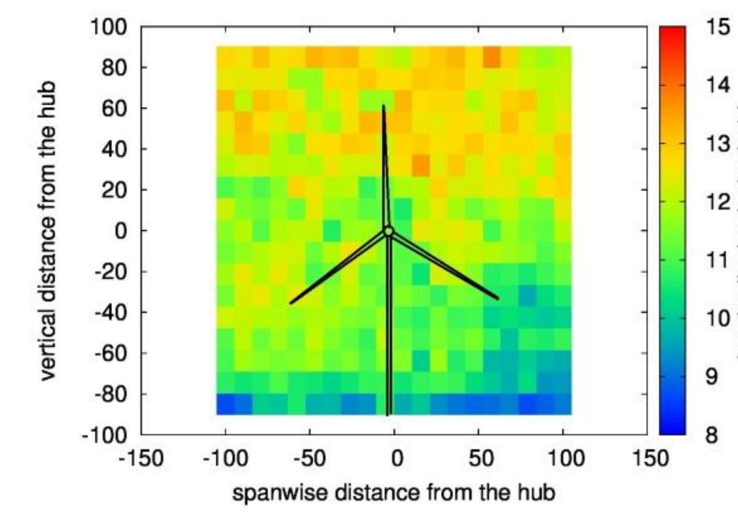


Figure 1 Instantaneous wind from TurbSim

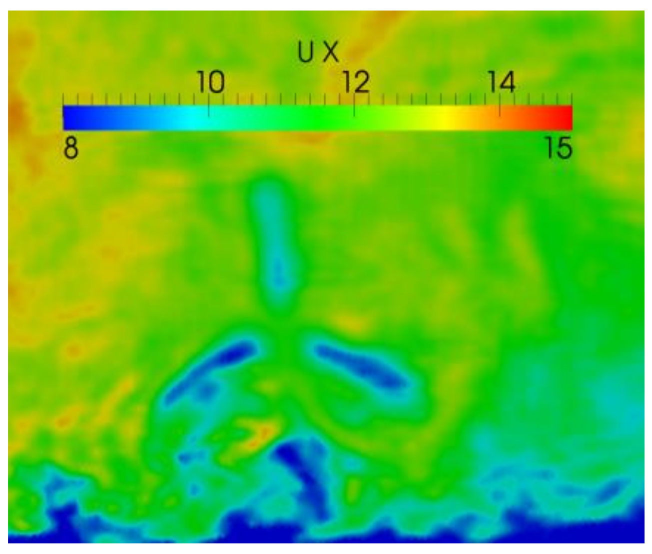


Figure 2 Instantaneous wind from SOWFA

More than a spatial and temporal coherence of the air flow corresponding to a better representation of physical processes the LES shows the influence of the turbine's movement in consequence of the actuator line model (figure 1 and 2).

Mean values

- pitch angle shows the most significant difference, because instantaneous wind speed exceeds regularly rated wind speed
- generator torque shows hardly any difference because of the proximity to the rated wind speed

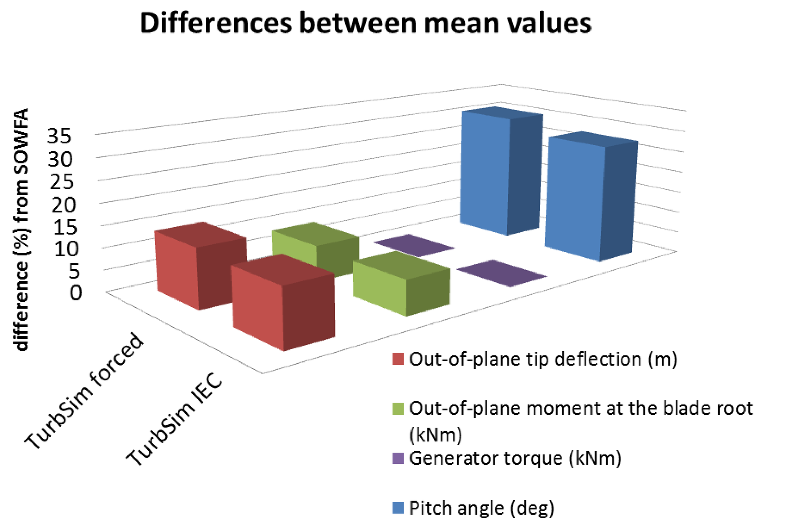


Figure 3 Mean value comparison of selected FAST outputs

Standard deviation

- error is generally more important due to the differences in the distribution of the fluctuations
- TurbSim provides at same turbulence intensity less energy and therefore lower standard deviations than SOWFA
- standard deviation difference is negative for TurbSim IEC

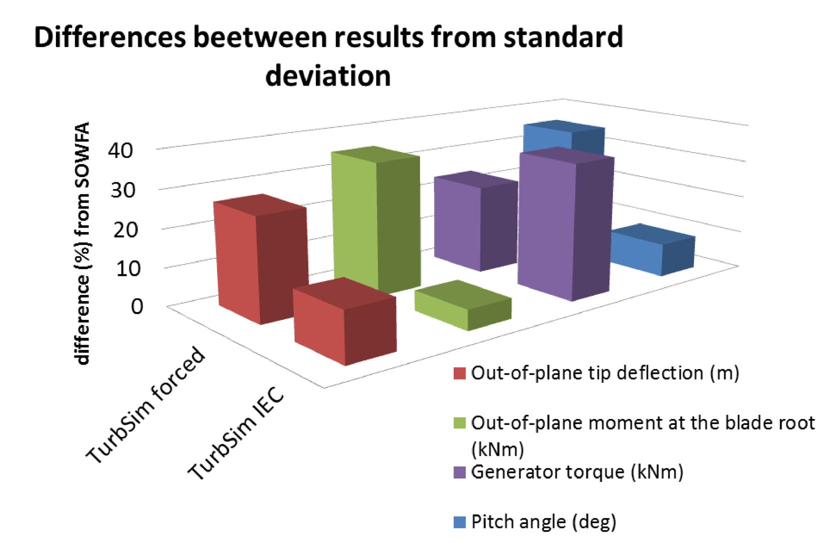


Figure 4 Standard deviation comparison of selected FAST outputs

DEL

- same trend as that of the standard deviation because these parameters are mathematically related
- more than 30 % diff. between results based on wind from TurbSim with IEC recommendations and those based on a well resolved LES

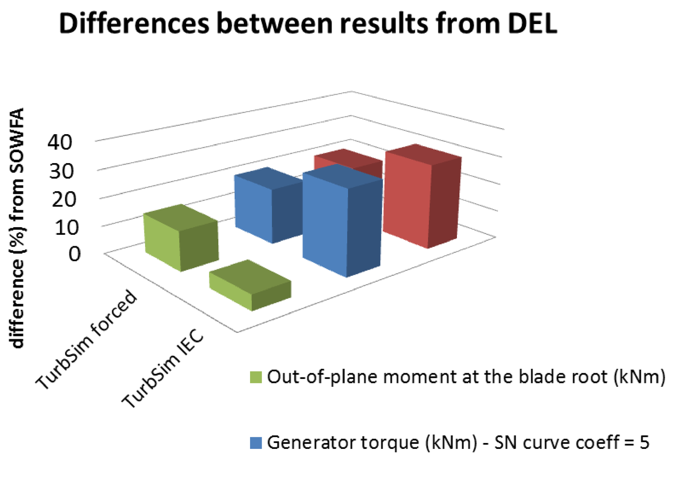


Figure 5 DEL comparison of selected FAST outputs

Conclusion

- instantaneous wind fields show less spatial and temporal coherence for TurbSim, SOWFA's wind fields are also influenced by turbine's mouvements
- differences in turbulence distributions have direct influence on the pitch angle. Hence outputs from aero-elastic show differences of 30 % and more, important differences occur even for mean values.
- LES is a promising simulation tool, but needs a high CPU consumption

References

1. Frandsen ST. (2007): *Turbulence and turbulence generated structural loading in wind turbine clusters,* phd, Risø National Laboratory, Denmark, 135p
2. Churchfield MJ, Lee S, Michalakes J, Moriarty PJ (2012), *A numerical study of the effect of atmospheric and wake turbulence on wind turbine dynamics,* Journal of Turbulence 13
3. IEC 61400-1 International standard for wind turbines: Design Requirement

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