Project title	Aerodynamic loads on rotor blades
Project number	TG2-1
Organisation	Chalmers University of Technology, Fluid Dynamics Division
Project leader	Professor Lars Davidson
Other participants	Hamidreza Abedi (PhD student)
Report for	2014-10-01 – 2016-09-30
Participating companies	GE Wind

Project description

The aim of the project is to develop computational methods for predicting unsteady aerodynamic loads on wind turbine rotor blades. The focus of the project is to handle transient loads by the Vortex Method in which tabulated lift and drag coefficients are used.

A time-marching vortex lattice free wake (VLFW) based on the incompressible, inviscid and irrotational flow has been developed to study the aerodynamic loads. It is based on the potential flow where it is coupled to the tabulated airfoil data and a semi-empirical model to take into account the viscosity and the dynamic stall effects, respectively. In addition, a module has been added to the developed vortex code for increasing its application range by handling all type of turbine components movements (both translation and rotation) through the simulation such as cone angle, shaft tilt, nacelle and etc.

The implemented vortex method has been validated by comparison with the Blade Element Momentum (BEM) method, the GENUVP code by National Technical University of Athens (NTUA), Hönö turbine measurement data and MEXICO wind tunnel measurements.

A new module has been added to take unsteady incoming flow into account using either a time series of turbulent wind field, generated by Large-Eddy Simulation, or Taylor's hypothesis (Frozen turbulence), provided by spectral model. This has been done in cooperation with the project Fatigue Loads in Forest Regions (TG2-2) generating turbulent fluctuations in atmospheric boundary layers both with and without forest.

Results

The effect of the skewed wake, due to the yaw misalignment, on the wake aerodynamics of wind turbine has been studied using the VLFW method. The results are compared with the MEXICO wind tunnel measurements where there is a quite good agreement between the simulation and experimental data. Particularly, it has been found that in addition to power reduction of the wind turbine due to the yawed flow, there is a periodic load variation along the rotor blade which accordingly increases the fatigue load.

Furthermore, three different methods called the standard potential method, the 2D static airfoil data method and the dynamic stall method have been introduced to calculate the aerodynamic loads. The results are compared with the MEXICO experiment, the BEM method and the GENUVP code. It is shown that for more accurate load and power prediction, coupling to the 2D static airfoil data is necessary even though some complex conditions such as separated flow, stall condition and centrifugal forces cannot be well predicted. For the non-yawed flow, a considerable discrepancies between the VLFW simulations and measurement data close to the blade root (inboard sections) may be physically explained due to the thick airfoil profiles which consequently results in the flow separation and stall condition even if at lower wind velocities. This is also certified for the NREL 5-MW machine. For the yawed flow, the difference between the maximum peak position of the normal forces along the rotor blade induce an additional moment on the rotor due to the yaw misalignment. Additionally, for almost all spanwise sections, the simulation presents a phase shift against the experiments for both the normal and tangential forces, nevertheless it predicts the azimuthal load variation rather well.

To predict the load and wake evolution under the realistic flow field around the wind turbine, in cooperation with TG2-2, time-dependent turbulent inflow fields (generated by LES and spectral model for both non-forest and forest regions) have been used as input data for the developed vortex method in-house code. The results show that presence of forest canopies decreases the mean power, and increases the standard deviation of the fluctuating power production. This certifies dependency of the inflow turbulence intensity and power production of a wind turbine.

Fulfilment of SWPTC's goals

In the project, methods for more accurate prediction methods of aerodynamic loads are developed. This will lead to:

- lighter wind turbines
- increased lifetime of wind turbines
- reduced maintenance costs

Deviations from project plan

There is no deviation from the project plan.

Publications

- Enhancement of free vortex filament method for aerodynamic loads on rotor blades, Proceedings of ASME 2014 International Mechanical Engineering Congress and Exposition, 14-20 November 2014, Montreal, Canada.
- Numerical Studies Of the Upstream Flow Field Around A Horizontal Axis Wind Turbine, 33rd ASME Wind Energy Symposium, 5-9 January 2015, Florida, USA.
- Development of free vortex wake model for wind turbine wake aerodynamics under yaw condition, 34th Wind Energy Symposium, 4-8 January 2016 San Diego, USA.
- Development of free vortex wake model for wind turbine wake aerodynamics under yaw condition, 34th Wind Energy Symposium, 4-8 January 2016 San Diego, USA.
- Assessment of the influence of turbulent inflow fields on wind-turbine power production, Journal of Wind Energy (under submission process), 2016/2017.
- Enhancement of free vortex filament method for aerodynamic loads on rotor blades. Submitted to Journal of Solar Energy Engineering, 2016.
- Development of Vortex Filament Method for Wind Power Aerodynamics, PhD thesis in Thermo and Fluid Dynamics, Department of Applied Mechanics, Chalmers University of Technology, Göteborg, 2016.

External activities

- Visiting National Technical University of Athens (NTUA), from 09-Mar to 03-Apr 2015, Athens, Greece.
- Project presentation, Vindkraftsforskning i fokus konferens, 6-7 October 2015, Uppsala, Sweden.
- PhD disputation presentation, Chalmers University of Technology, 15 April 2016, Göteborg, Sweden.
- The Science of Making Torque from Wind (TORQUE 2016), 5-7 October 2016, Munich, Germany.