Improvement of efficiency and fatigue life of vertical-axis wind turbines

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Problem statement
The fast growing demand for wind energy has led to a wide variety of wind turbine designs. A specific contemporary type is the vertical-axis wind turbine (VAWT), where the rotor shaft is oriented vertically and the generator and gearbox are placed at the base of the turbine, as shown in Figure 1. Compared with horizontal-axis wind turbines, VAWTs are generally considered more capable of handling highly turbulent, gusty wind conditions and rapidly changing wind directions. Since these conditions are commonly encountered in urban environments, this type of wind turbine can play a vital role in urban wind energy. On the downside, however, VAWTs are up to now generally less efficient and can be more prone to fatigue.

Objectives
In the present research two important aspects for the design of VAWTs will be studied:
- The efficiency of the systems’ energy conversion
- Its fatigue life under gusty wind

The efficiency depends on the short-term time scale, dynamic interactions between the airflow and the turbine structure; fatigue life is related to the long-term formation of cracks and deformations under a large number of load cycles. Most research in the past has studied these aspects separately. Development of a solver in which processes on both scales are taken into account is expected to lead to a new design of VAWTs with better efficiency and durability.

Methodology

Fatigue modelling
- Interface elements equipped with a cohesive zone model (CZM) will be adopted to model the progressive fatigue damage of blades under increments of load cycles caused by complex wind conditions.

FSI (Fluid-structure interaction) modelling
- The wind flow will be modelled using either the transition Shear Stress Transport (SST) k-ω model or Detached Eddy Simulation (DES) modelling approach; ABL wind tunnel experimental data will be used to validate simulation results.

Coupling process
- The outputs of both models above will be coupled at predefined instants in time. Material degradation derived from the fatigue response can be used as input data for the FSI simulation at a specific time instant, and force spectra from FSI modelling will serve as input for the next load cycle interval of fatigue analysis, as shown in Figure 2.

Current results
The transverse failure behavior of a single fiber epoxy system under a quasi-static axial loading has been analyzed. The crack development is simulated by the cohesive zone model. In parallel, the optimal computational settings for accurately estimating drag and lift coefficients of an airfoil have been explored at a wide range of angles of attack. Figure 3 shows an initial crack pattern and the corresponding horizontal normal stress (left), together with a 2D pressure profile of a blade using a standard k-ε turbulence model (right).