Development and Numerical Investigation of an Actuator Concept for Shape-Adaptive Airfoil Profile for Horizontal Axis Wind Turbine Rotor

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Long Abstract

Abstract

To cope with the increase in demand on renewable energy, the modern horizontal axis wind turbines have grown in dimension and have already reached a rotor diameter of 150 meter. With the introduction of offshore wind parks, the door to extract multi megawatt power from wind is opened and has set a trend of continuing increase in wind turbine rotor diameter. This imposes a trade-off between the energy production and the control-ability of future wind turbines. The increase in rotor diameter results in higher torque requirement on the active pitch/stall- control motor. Moreover, it is difficult to achieve optimal inflow condition over the entire span length for rigid blades. This results in high structural loading, which in turn reduces the life span of the blades. In light of this situation, smart rotor blades with local airfoil form-adaption promises to be an alternative and effective control scheme for future wind turbines. The authors present the results of investigations on active airfoil form-adaption concept for wind turbine rotor blades. A novel actuator concept is developed for incorporating airfoil trailing edge form-adaption in wind turbine application. Structural analysis of the shape morphing system is carried out and the aerodynamic performance of the shape-adaptive airfoil is presented.

Introduction

Modern wind turbines run mostly at variable rotational speed and use collective pitch control to optimize the energy yield and blade loading. The larger swept area in future wind turbines means the blades would be more susceptive to changing inflow conditions and wind shear. In light of this situation, collective or even individual pitch control alone would not be able to fully tame the radial and azimuthal gradient of the inflow. To compensate, future mega-watt rated wind turbines would require a faster yawing and pitching mechanism which would lead to increased loading on the entire structure. An alternative solution is the introduction of shape-morphing airfoil sections which would allow faster and more detailed flow control over different spanwise locations of the rotor blades.

In scope of this investigation, the airfoil trailing-edge camber adaption is selected as the shape adaption strategy to develop the actuator system. This allows the performance optimization of the airfoil profile for fixed incidence angle as well as perfomance evaluation of the morphed profile for varying inflow conditions.

1. Actuator Concept

This work focuses on the development of an actuator to actively adapt the shape of the airfoil trailing edge section of horizontal axis wind turbine rotor. In a first step, a number of criteria is defined for the selection of the actuator for wind turbine application. The actuator module needs to be compliant with existing wind turbine blade structure, light-weighted, and non-susceptive to lightning attacks. Taking into consideration all the above criteria, a novel actuator concept is proposed to adapt the airfoil profile shape by changing the trailing edge camber. The actuator is modelled as a kinematic module. Inward- protruding beam sections are connected at different axial positions of the upper and lower skins of the form-adaptive section. The kinematic module is able to rotate around its axis and has a cam profile which determines the actuation forces exerted on the different beam sections. The actuation force is achieved through implementing a torque which translates in a coupled bending moment on the profile upper and lower skins. The skins of the shape-adaptive airfoil section are modelled to be made of elastic material.

2. Methodics

A staggered fluid-structure interaction scheme is used to numerically simulate the shape-adaptive system. The simulation of the aerodynamic flow field is carried out using the airfoil panel method code XFOIL [1]. The XFOIL code employs linear-vorticity stream function panel method coupled with viscous formulation of the flow-field via integral boundary layer method [2]. The structural simulation is performed using finite element simulation software CalculiX CrunchiX [3].

At first, the 2D viscous flow field around the airfoil is simulated with the help of XFOIL. In the next step, structural simulation of the morphing structure under aerodynamic and actuation forces is performed using CrunchiX [3]. The deformed shape of the airfoil profile is then used for a second aerodynamic simulation via XFOIL. The resulting aerodynamic forces are then incorporated in further structural simulations to recalculate the required actuation forces.

A parametric study is conducted to determine the shape and the position of the cam profile, the dimensions and relative positions of the beam elements, the required actuation torque, and the material characteristics of the airfoil skin to achieve optimal profile pressure distribution for the morphed airfoil shape.

References

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