

Thesis for Master's Degree in Aerospace and Astronautical Engineering

Aerodynamic Design and Preliminary Aeroelastic Analysis of a 50 kW horizontal-axis wind turbine rotor

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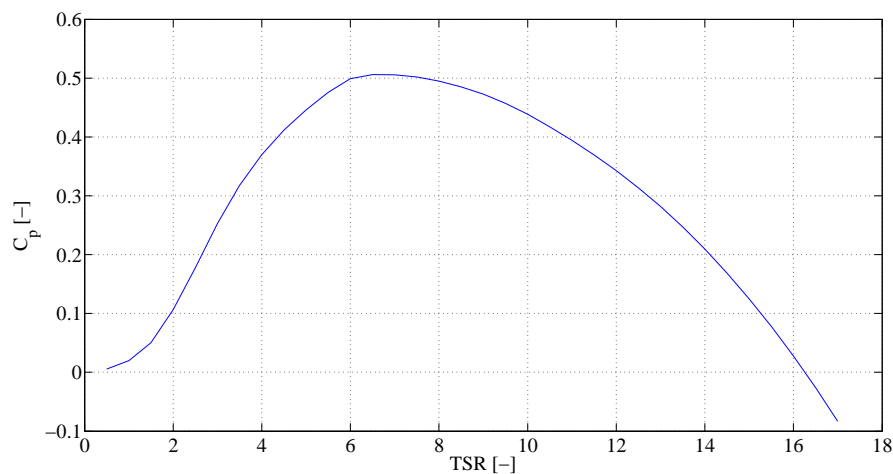
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Abstract

This work concerns the aerodynamic design and a preliminary aeroelastic analysis of a 50 kW horizontal-axis wind turbine, with an active pitch control device.

The first part concerns the blade aerodynamic design, based on an high efficiency criterium, in terms of power coefficient, which requires the study of both an accurate external shape, i.e. chord and pitch distributions, and a particular design of airfoil along the span in order to enhance the maximum efficiency performance for a specific optimal aerodynamic load, computed via GLAUERT theory. From some general considerations, i.e. the dependence of blade main performance parameters, as power coefficient C_P and starting torque performance - that have opposite requirements, from the variation of main aerodynamic parameters, both in lift and drag curves, of a single airfoil for all the blade, has been possible to distinguish among several airfoil couple (thicker at root, thinner at tip) that could maximize the performance parameters.

At this point has been made a choice in order to simplify the blade external shape, trying to have a linear chord distribution, that leads to a law for the optimal lift coefficient in each section. For this lift coefficient values has been design several special airfoils, via an optimization tool based on gradient method, developed at DIAS: these airfoils reach their maximum aerodynamic efficiency at about the optimal lift coefficient computed for the specific section.

Power coefficient vs TSR

With these airfoils has been possible to gain a power coefficient greater than the one expected in preliminary design, and at the same time has been obtained a very interesting starting performance, to reduce strongly the wind speed necessary to starts generator rotation, and also the power production.

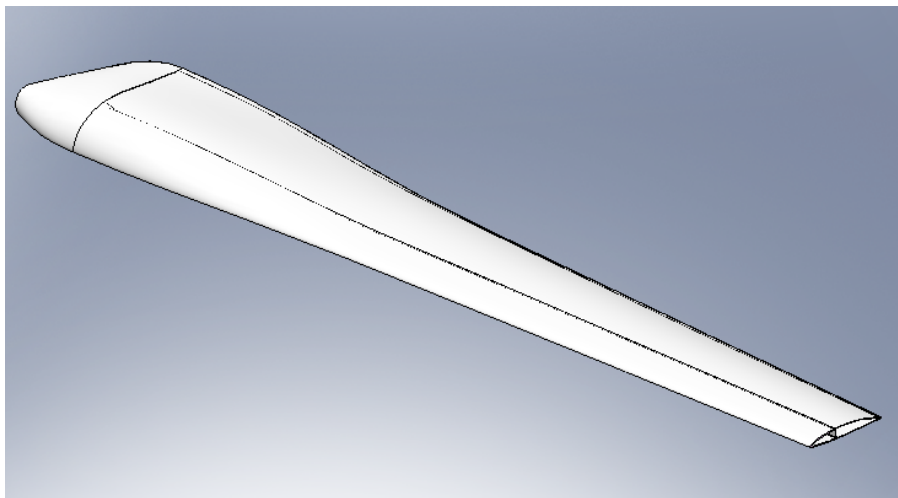
Special airfoils characteristics give us the chance of reaching very good performance even in forced transition at leading edge, a situation that simulates high turbulent flow and debris on blade, at least equal to those ones expected in preliminary sizing, i.e. with a loss of only 10% respect to nominal conditions.

The second part concerns a preliminary evaluation of stresses along the blade, due to aerodynamic and centrifugal forces, via DE SAINT VENANT theory in very severe load conditions, most of all for stress margins of safety and maximum deflections in order to estimate the clearance between hub and tower. The whole has been realized with a MATLAB code, with a simple GUI, that allows drawing blade sections with several components as spars, flange, local thickening, etc. end then computing centre of gravity and shear centre position, and beyond stiffness characteristics: in this way is possible to drawing sections that contemplate both lightness and stiffness requirements.

During these analysis has been found a margin of safety for stress, due to both bending moment introduced by aerodynamic load and normal stress produced by centrifugal force, that is higher than that expected by regulations. The maximum deflection value in parking condition, a situation where there's not the centrifugal-induced stiffness, is accetable for clearance.

The introduction of a flapping motion dynamic analysis has allowed to estimate, even in nominal condition only - for which could be done some linearization in the equations, the reduction of statical blade deflection caused by centrifugal force.

The final blade shape could not be irrespective of pitch control axis location, which affects the coupling between flapping and feathering motion, that could leads to instability phenomena, both static and dynamic, as divergence and flutter. Proceeding to stability analysis for several blade configurations, with a blade equivalent model, has been determined a specific position for pitch control axis for which no flutter occurs for every operating free-strem speed and a wide range of angular velocity.



Blade final shape