Numerical Simulation of the 3D Laminar Viscous Flow on a Horizontal-axis Wind Turbine Blade

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Abstract

The aim of this paper is to describe the methodology followed in order to determine the viscous effects of a uniform wind on the blades of small horizontal-axis wind turbines that rotate at a constant angular speed. The numerical calculation of the development of the three-dimensional boundary layer on the surface of the blades is carried out under laminar conditions and considering flow rotation, airfoil curvature and blade twist effects. The adopted geometry for the twisted blades is given by cambered thin blade sections conformed by circular are airfoils with constant chords. The blade is working under stationary conditions at a given tip speed ratio, so that an extensive laminar boundary layer without flow separation is expected. The boundary layer growth is determined on a non-orthogonal curvilinear coordinate system related to the geometry of the blade surface. Since the thickness of the boundary layer grows from the leading edge of the blade and also from the tip to the blade root, a domain transformation is proposed in order to solve the discretized equations in a regular computational 3D domain. The non-linear system of partial differential coupled equations that governs the boundary layer development is numerically solved applying a finite difference technique using the Krause zig-zag scheme. The resulting coupled equations of motion are linearized, leading to a tridiagonal system of equations that is iteratively solved for the velocity components inside the viscous layer applying the Thomas algorithm, procedure that allows the subsequent numerical determination of the shear stress distribution on the blade surface.

Keywords: Three-dimensional Boundary Layer; Wind Turbine Blade; Laminar Flow; Viscous Shear Stress; Generalized Curvilinear Coordinates; Finite-difference Technique