Aeroservoelasticity of Wind Turbines

This thesis deals with the fundamental aeroelastic interaction between structural motion, pitch action, and control for a wind turbine blade. As wind turbines become larger, the interaction between pitch action, blade motion, aerodynamic forces, and control becomes even more important to understand and address. The main contribution of this thesis is the development of an aeroelastic blade model which, on the one hand, includes the important effects of steady state blade deformation, gravity, and pitch action, and, on the other, is transparent, suitable for analytical analysis and parameter studies, and furthermore linear and therefore suitable for control design. The development of the primary aeroelastic blade model is divided into four steps: 1) Nonlinear partial differential equations (PDEs) of structural blade motion are derived together with equations of pitch action and rotor speed; the individual terms in these equations are discussed and given physical interpretations; 2) Steady state blade deformation and induced velocities are computed by combining the PDEs with a steady state aerodynamic model; 3) Aeroelastic modes of motion are computed by combining the linearized PDEs with a linear unsteady aerodynamic model; this model is used to analyze how blade deformation affects the modes of motion; and 4) the linear aeroelastic blade model is derived by a modal expansion of the linearized PDEs combined with a linear unsteady aerodynamic model. The aeroelastic blade model has many similarities to a 2D blade section model, and it can be used instead of this in many applications, giving a transparent connection to a real wind turbine blade. In this work the aeroelastic blade model is used to analyze interaction between pitch action, blade motion, and wind speed variations. Furthermore, the model is used to develop a state estimator for estimating the wind speed and wind shear, and to suggest a load reducing controller. The state estimator estimates the wind shear very well and the load reducing controller is capable of reducing flapwise blade motion caused by wind shear with 75% under ideal conditions. So, a new aeroelastic blade model has been derived, which includes important features of large wind turbines, yet simple enough to be suitable for analytical analysis and control design.

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