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A Spatial Repetitive Controller Applied to an Aeroelastic Model for Wind Turbines

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Abstract : This paper presents a nonlinear differential model, for a three-bladed horizontal axis wind turbine (HAWT) suited for control applications. It is based on a 8-dofs, lumped parameters structural dynamics coupled with a quasi-steady sectional aerodynamics. In particular, using the Euler-Lagrange Equation (Energetic Variation approach), the authors derive, and successively validate, such model. For the derivation of the aerodynamic model, the Greenbergs theory, an extension of the theory proposed by Theodorsen to the case of thin airfoils undergoing pulsating flows, is used. Specifically, in this work, the authors restricted that theory under the hypothesis of low perturbation reduced frequency k, which causes the lift deficiency function C(k) to be real and equal to 1. Furthermore, the expressions of the aerodynamic loads are obtained using the quasi-steady strip theory (Hodges and Ormiston), as a function of the chordwise and normal components of relative velocity between flow and airfoil Ut, Up, their derivatives, and section angular velocity ε˙. For the validation of the proposed model, the authors carried out open and closed-loop simulations of a 5 MW HAWT, characterized by radius R =61.5 m and by mean chord c = 3 m, with a nominal angular velocity Ωn = 1.266rad/sec. The first analysis performed is the steady state solution, where a uniform wind Vw = 11.4 m/s is considered and a collective pitch angle θ = 0.88◦ is imposed. During this step, the authors noticed that the proposed model is intrinsically periodic due to the effect of the wind and of the gravitational force. In order to reject this periodic trend in the model dynamics, the authors propose a collective repetitive control algorithm coupled with a PD controller. In particular, when the reference command to be tracked and/or the disturbance to be rejected are periodic signals with a fixed period, the repetitive control strategies can be applied due to their high precision, simple implementation and little performance dependency on system parameters. The functional scheme of a repetitive controller is quite simple and, given a periodic reference command, is composed of a control block Crc(s) usually added to an existing feedback control system. The control block contains and a free time-delay system eτs in a positive feedback loop, and a low-pass filter q(s). It should be noticed that, while the time delay term reduces the stability margin, on the other hand the low pass filter is added to ensure stability. It is worth noting that, in this work, the authors propose a phase shifting for the controller and the delay system has been modified as e^(−(T−γk)), where T is the period of the signal and γk is a phase shifting of k samples of the same periodic signal. It should be noticed that, the phase shifting technique is particularly useful in non-minimum phase systems, such as flexible structures. In fact, using the phase shifting, the iterative algorithm could reach the convergence also at high frequencies. Notice that, in our case study, the shifting of k samples depends both on the rotor angular velocity Ω and on the rotor azimuth angle Ψ: we refer to this controller as a spatial repetitive controller. The collective repetitive controller has also been coupled with a C(s) = PD(s), in order to dampen oscillations of the blades. The performance of the spatial repetitive controller is compared with an industrial PI controller. In particular, starting from wind speed velocity Vw = 11.4 m/s the controller is asked to maintain the nominal angular velocity Ωn = 1.266rad/s after an instantaneous increase of wind speed (Vw = 15 m/s). Then, a purely periodic external disturbance is introduced in order to stress the capabilities of the repetitive controller. The results of the simulations show that, contrary to a simple PI controller, the spatial repetitive-PD controller has the capability to reject both external disturbances and periodic trend in the model dynamics. Finally, the nominal value of the angular velocity is reached, in accordance with results obtained with commercial software for a turbine of the same type.

Keywords : wind turbines, aeroelasticity, repetitive control, periodic systems
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