Experimental Investigation of Dynamic Load Control Strategies using Active Microflaps on Wind Turbine Blades.

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Abstract body:

Conventional wind turbine rotor blades are exposed to unsteady aerodynamic loads caused by wind gusts. Typically, the wind gusts have a duration of 1s to 10min, whereby maximum wind gusts with speeds 1.7 times faster than the hourly mean wind speed can occur [1]. These dynamic loads lead to undesired responses of the blade flap and chord-wise oscillations. The lifetime of a blade is significantly reduced by fatigue due to this effect. Furthermore, the tower is adversely affected by the resulting rotor dynamics. A proper way to minimize unsteady aerodynamic loads on rotor blades is to apply active flow control elements. Such solutions however require appropriate sensors and control strategies in order to ensure a stable operation. Designing a conventional controller for active flow control elements on a real wind turbine blade requires a very large amount of physical insights. However, the aerodynamics and aeroelastic effects on wind turbine blades are not yet well understood. Because of this lack, a feasible way of designing a controller is to use the so-called black box method. Thereby the controller is designed by observing inputs and outputs without taking into account the dynamics in between.

This paper includes results from experiments with active dynamic load control using microflaps at the trailing edge of wind turbine blades. Thereby the focus of the research was the design of several controllers based on neural networks and the comparison to a conventional PID-Controller. A control system consisting of a force sensor, an angle of attack sensor, a controller and the microflap as an actuator was designed and tested in a wind tunnel. For this purpose a test wing with constant cross section, based on the dedicated wind turbine airfoil AH 93-W-174 [2] was equipped with a trailing edge microflap with a flap-chord of 1.6%c. Measurements were accomplished at the large wind tunnel of the Herman Föttinger Institute (HFI) of TU-Berlin. Wind gusts were simulated by varying the angle of attack of the airfoil model in a range of -10° to 15° with a maximum angular velocity of 2.2°/s. The microflap could be deflected simultaneously in a range of ±80° with a deflection speed of ca. 300°/s. The flap deflection was achieved by digital servos mounted on the blade. All measurements were accomplished at a constant Reynolds number of 10^6.

In a first step a system identification process was accomplished. In order to capture the dynamics of the system a PRBS (Pseudo Random Binary Sequences) was applied to angle of attack and flap deflection. At the same time the resulting dynamic forces were measured with a six-component wind tunnel balance [3]. The sampling rate of all the measured parameters was 7Hz. Figure 1 shows the measured data in a polar plot. Considering a fixed operation point below stall, the flap can compensate for an angle of attack change of ±3°. At post stall the control authority is less and only achieved by deflection of the flow coming from the pressure side since the suction side of the flap operated in separated flow regime. It is also seen that the same flap deflection at the same angle of attack does not result in the same lift for different data points. This is due to the unsteady flow created by the variation of the angle of attack. The flow is affected by its history, which has to be considered in the control strategies.

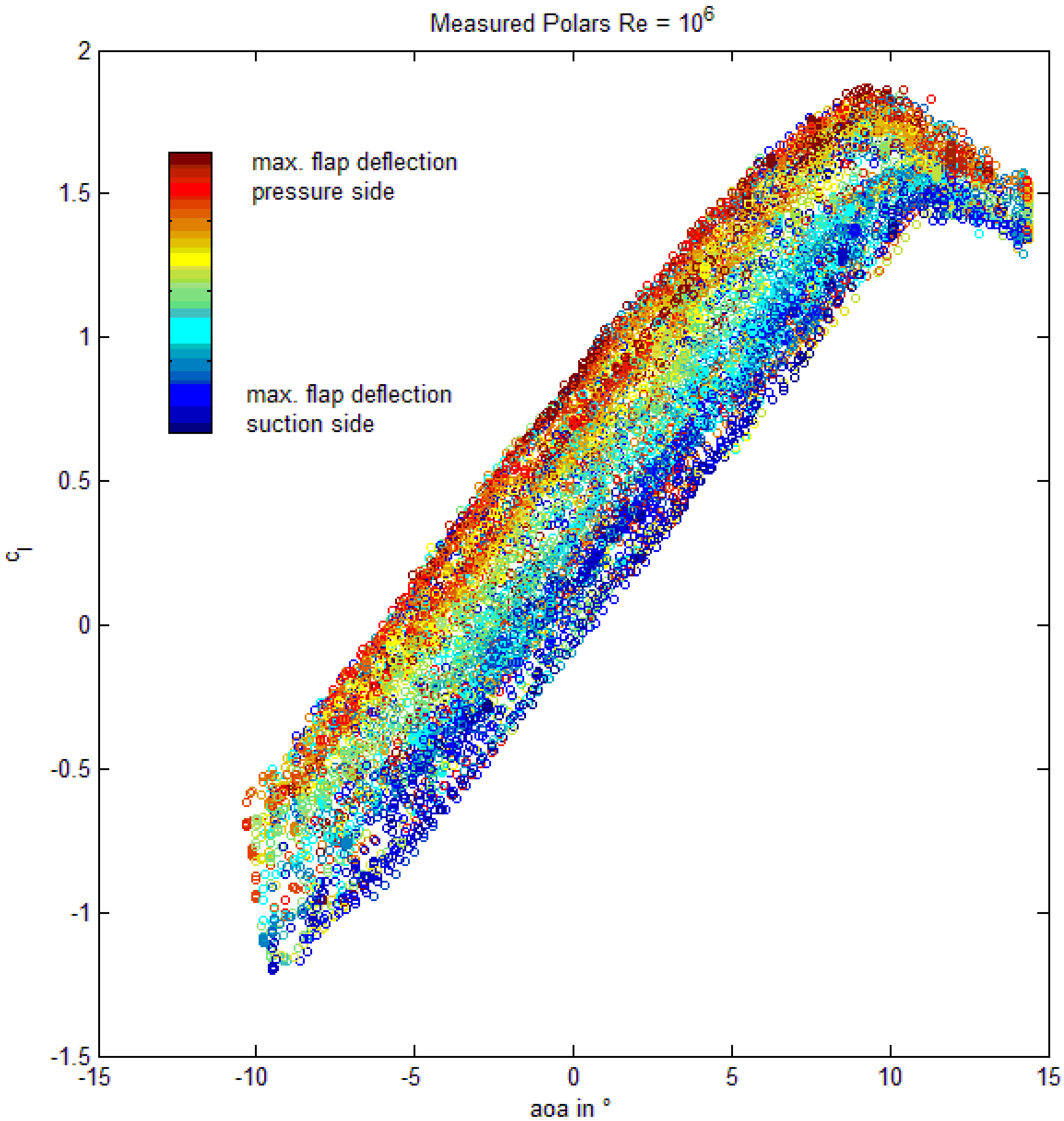

Figure 1: *Dynamically measured polars at Re=10^6*

A part of the captured data was used for the training of a neural networks using the NNSYSID toolbox of Nørgaard [4], whereas another part was used for validation of the obtained neural networks. The network with the smallest validation error was selected. Furthermore, a pruning algorithm was applied in order to minimize the error of the network in terms of unseen input data. Thus, a mathematical model was obtained representing the dynamics of the real system. Furthermore, an inverse model of the system was achieved by teaching a second network. Figure 2 shows the system output, in this case c_l, at varying flap positions and angle of attacks, of the real experimental system (solid) compared to the output predicted by the forward neural network (dashed). This figure shows that the achieved mathematical model performs very well and can be used for further controller design and simulation.

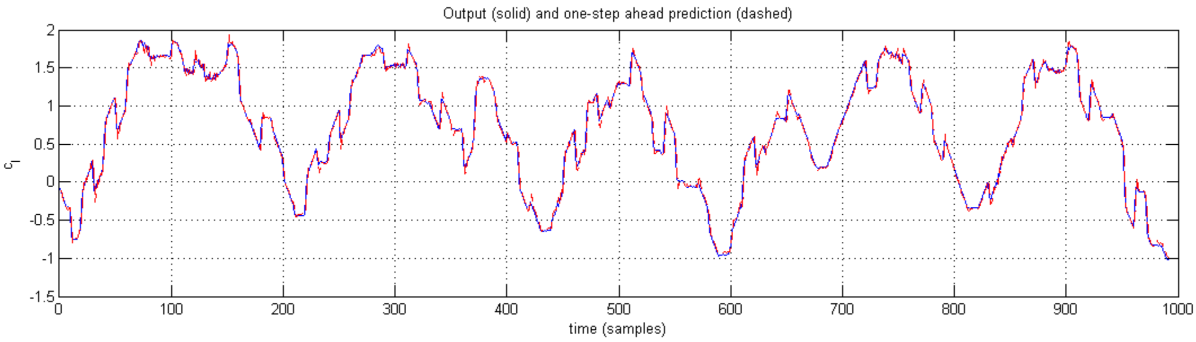

Figure 2: *Neural Network output (red dashed) vs. real experimental System output (blue solid) for 1000 samples*

In a second step different controllers based on neural networks were designed and applied to the real experimental system. Feed-forward as well as closed loop controllers were considered. Figure 3 shows a neural network-based Direct Inverse Controller (DIC). An inverse model neural network is directly used as a controller, whereas past control outputs and inputs as well as the reference are used as controller inputs.

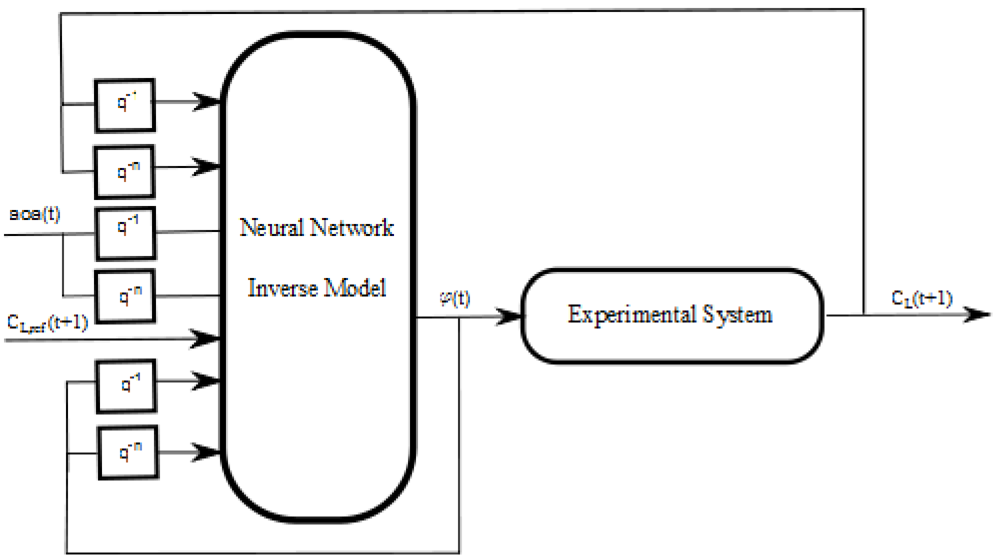

Figure 3: *Direct Inverse Controller.*

The Implementation of the controllers were done in NI Labview while a 24bit A/D-converter (NI 9219) served for data acquisition. The communication with the servos was achieved using a micro controller (Micro-Maestro 6-channel USB-Servo Controller) connected with the USB-port of a PC. In order to realize real time control, data acquisition, controller and control output tasks were applied to different processor cores.

A constant lift was applied as reference to the controller in order to compensate lift variations caused by angle of attack changes. The controllers were compared to each other and PIV-measurements were accomplished in order to visualize the controlled flow-field.

Reference(s)

[1] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi, *2001*, *Wind Energy Handbook*, John Wiley & Sons

[2] Dieter Althaus, 1996, *Niedriggeschwindigkeitsprofile*, Vieweg Verlagsgesellschaft

[3] Robert K. J. Meyer, 2000, *Experimentelle Untersuchungen von Rückstromklappen auf Tragflügeln zur Beeinflussung von Strömungsablösungen,* Mensch & Buch Verlag

[4] Magnus Nørgaard, http://www.iau.dtu.dk/research/control/nnsysid.html, (August 2010)