Load alleviation and performance optimization using smart blades

State-of-the-art modern multi-MW wind turbines operate in variable rotor speed and are equipped with full-span pitch control for power regulation in above rated conditions. Individual pitch control is the latest technology that is implemented in prototypes, in order to cope with periodic global loads on the rotor. The large multi-MW blades can limit the speed of the pitch actuator needed for load reduction control. Also, the excessive use will lead to wear of the pitch bearings and actuator. Furthermore, more distributed control is required in order to achieve considerable load reduction of the fluctuations in the asymmetric inflow field of large rotors. Active control based on real-time measured quantities (being loads, accelerations or inflow states) can deal with fast changes in aerodynamic loads. This is the target of the 'Smart Rotor research which is investigated in DUWINDs research programs. By smart rotor control, the active aerodynamic load control by using distributed devices with built-in intelligence is meant. More detailed and fast aerodynamic control can contribute to the challenges associated with unsteady phenomena and deal with stochastic components. Small, low inertia aerodynamic surfaces can both result in fast control reaction time and distributed control over the asymmetric incoming wind field. The advances in aerodynamics, materials and control technology have contributed to the development of such systems. The Duwind research has adopted trailing edge flaps as control devices. Feasibility studies as well as windtunnel measurements have shown a reduction of the fatigue-damage-equivalent load of 40-60 percent. Demonstrating hardware (being a part of a blade) are under construction.

The main target of this Smart Turbine research programme is to perform design optimization studies on a large turbine equipped with smart control capabilities. We consider an horizontal-axis upwind or downwind rotor with a diameter of 150 m (10 MW power range) with two and three blades.

The first step is optimization of the rotor geometry, spanwise length and placement of aerodynamic control devices, placement of sensors and general operation strategy. Attention is put for correct representation in the scaled down model. Using real-time control hardware various control schemes and load cases are investigated. Experimental data processing is performed and results are compared with the numerical studies. Conclusions are drawn based on physical insight gained, and a choice for the configuration for the next step is made.

The next step is to implement this new rotor technology in the preliminary design of a turbine. Not only the fatigue load is taken into account, but also extreme loads, in order to verify whether the advantages for fatigue load reduction are not overruled by consequences for extreme load control. Furthermore the smart control has to become part of the turbine control and safety system. In particular the consequences for the safety system have to be analyzed. This is done for the 5MW UpWind reference turbine that is used in many European (UpWind) and USA (NREL) studies.

An upscaled version (10 to 20MW) of this reference turbine, developed already in previous DUWIND programs is taken as basis for the upscaled Smart Turbine. More detailed studies are performed optimizing the structural integrity (in more detailed structural level, possibly using a FEM tool), the blade aerodynamic shape, and the integrated power regulation and (distributed) load alleviation control systems. The achieved load alleviation in fatigue and extreme load cases is analyzed, and the consequences for the load-carrying components like the pitch bearings, yaw-system, tower-top loads and support structure loads.

Finally, the most critical aspects of wind turbine technology are addressed: reliability and cost of energy. All benefits of the smart technology disappear when the reliability of the turbine is compromised. A system reliability analysis will be undertaken, and consequences for operation and maintenance are quantified. Finally an analysis of the cost of energy, compared to the current state of the art turbines, will show the potential for further developments.