SMART ROTOR AND CONTROL CONCEPTS

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1. Introduction : Evolution of wind turbine control systems

Wind turbines become larger and larger. Modern wind turbines designed for offshore application have become the largest rotating machines on earth, with the length of one blade almost equal to the entire span of a Boeing 747. This upscaling has, until now, not led to significant changes in the blade structure: all blades are constructed as one single component, with the blade skin as load carrying element. On the contrary, the control of the blade loads has changed in the past. Until the nineties in the previous century, the 'Danish concept' was very successful. The turbines making use of this concept combine constant rotor speed with stall of the flow around the rotor blades: increasing wind speeds automatically induce increasing drag forces that limit the absorbed power. All other control options were considered too complex, leading to the statement of a wind turbine manufacturer: 'the best control is no control'. The simplicity of this concept has certainly contributed to the success of the 'Danish concept', but evolution toward large rotor sizes appeared to be uneconomical.
Nowadays, all large wind turbines run at variable rotational speed, combined with the adjustment of the collective pitch angle of the blades to optimize energy yield and to control the loads. This is a big step forward: the control of the blade pitch angle has not only led to power regulation, but also to a significantly lighter blade construction due to the lower load spectrum and a lighter gear box due to shaved torque peaks. The next step in blade load control is almost ready for commercial application: pitch angle adjustment per blade instead of collective. This will further alleviate the rotor loads, specially the periodic loading due to yaw and wind shear. Not only will the blades benefit from this, but also the drive train and nacelle structure.

Besides these industrial developments, research institutions have investigated other methods for blade load alleviation right from the beginning of modern wind power. Principally, two methods exist to do so: passive and active. Passive load control is achieved when the (aero-) dynamic response of the rotor blades to changes in wind speed counteract these changes. With active control the blade loads are adapted, by adjusting the aerodynamic shape of the blades. Both types of load control will be presented, although emphasis is on modern developments in active load control. Individual pitch control is the most advanced active control that is nowadays applied.
A further step, probably for the 2020 wind turbine generation with even larger rotor size, possibly is a much more detailed and faster control of the loads. Control should be possible for each blade at any azimuthal position and any spanwise station, by aerodynamic control devices with embedded intelligence distributed along the span. The correspondence with the

control devices at airplane wings (flaps at leading and trailing edge, ailerons) is apparent, but the requirements for blade control devices are probably much more severe. Modern blades are very reliable, and require only limited maintenance at the blade pitch bearing. Future blades with distributed control devices should be as reliable, without adding maintenance requirements.

The development of this kind of technology, often named in popular terms 'smart structures' or 'smart technology', is an interdisciplinary development par excellence. It requires a joint effort in many disciplines:

- Aerodynamics of airfoils with control elements. Several options are available for the adjustment of lift and drag: flaps, microtabs, boundary layer suction or blowing or other means of influencing it, variable camber.
- Actuators. The activation of the aerodynamic devices has to be fast and reliable with as little as possible power use. Well known options are piezo-electric elements and shape-memory alloys.
- Control. The control algorithms for this type of control are not yet available. Fast, real time load identification algorithms, allowing application of predictive control techniques is a challenging task. Algorithms like self-learning and adaptive algorithms should be used to design a fault-tolerant controller.
- Communication and power supply. The power supply and communication between the control devices should not increase the sensitivity for lightning strikes.
- Blade material and construction. Preferably all devices should be embedded in the blade material, without creating slots in the blade surface to avoid contamination of the inner structure. The embedding can lead to new blade constructions, like the use of spars and ribs.
- Blade design tools. All available design tools do not include distributed control options, nor allow for totally different blade constructions.

A trade-off between active and passive systems is difficult to make. Passive systems like bend-twist coupling have the advantage that, once they work, they are inherently reliable and do not require maintenance. The drawback is that only limited adjustments are possible when the rotor is built, and that the aeroelastic stability requires special care. Active systems are much more complicated, but offer the possibility to control the load at any moment in time and at any radial position according to the specifications of the turbine operator.

A recent inventory of progress in research on these topics can be found in [32]. In the framework of the International Energy Agency an Expert Meeting was held on 'The application of smart structures for large wind turbine rotors'. The proceedings show a variety of topics, methods, solutions, which reflects the state-of-the-art: the research towards smart structure rotor technology has just started.