Robust aerodynamic control of large flexible wind turbines

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1. Background and aim

A commitment to a green energy future requires new complex engineering systems that reduce the cost of environmentally friendly power generation. Increasing the size of wind turbines is one of the most effective ways to achieve greater wind power generation capacity in a cost-effective way, as it reduces the number of generation sites and concentrates generation at optimal geographical locations. Fewer concentrations of larger machines will also reduce the installation and grid-connection costs. With a 164-m rotor diameter, the largest commercially-available turbine is the Vestas V164-7.0MW. The industry is aiming to build 20MW wind turbines with rotor diameter over 240 meters. However, large off-shore machines are encountering new technical challenges that increase their operating costs and restrict further performance improvements. The important one is the increased fluctuating loads under wind gusts. It is therefore particularly important to mitigate these loads, which reduce the life expectancy of the wind turbine components, in the offshore context, where maintenance is less easy and more expensive. Pitch control, changing the whole blade pitch from the root, is the main aerodynamic method for load control used in the wind turbine industry. However for the increasingly long blades being designed, pitch actuation is ineffective in controlling rapid loading changes due to atmospheric turbulence. The smart rotor concept which actuates smaller flaps deployed along the span of the blades offers a more effective system to alter the pressure distribution along the blades. Reducing the cost of turbine blades itself can only have an small effect on the energy cost, but if an innovative blade design can reduce the rotor loading, it will reduce significantly the general energy cost because the rotor loading affects the loading of other components such as the tower and drive-train (thus their required materials, maintenance costs and system reliability). This is the main motivation of "smart rotor" research.

All the current literature about smart rotors focuses on using trailing-edge flaps because their force and moment expressions are well known through aviation research. In a recent project looking at aerodynamic control of long-span suspension bridges using controllable flaps that draw on similar principals to smart rotors, the PI with collaborators at Oxford University and Imperial College have shown by theory and experiment that leading-edge flaps offer huge advantages for moment control and load reduction [2-3]. The PI also learnt from industry that it will be much easier to repair leading-edge flaps than trailing-edge ones because the engineers can access the leading-edge flaps more easily through the hole located at the leading edge. A disadvantage of leading-edge flaps is that they can introduce flow separation (thus introducing drag) and therefore round leading-edge flaps will need to be introduced, losing some aerodynamic efficiency to avoid flow separation, but still having much better performance than the trailing-edge flaps shown through the PI's recent wind tunnel tests [3].

The aim of this project is to evaluate the effectiveness of the leading-edge flaps on the fluctuating load reduction of the wind turbine blades based on 2-D analysis, by extending the PI's research results in [1-3]. It requires the knowledge of mathematical modelling, ODEs, stability, basic control theory & optimization and preliminary aerodynamics.

2. Programme

2.1 Based on 2-D Theodorsen theory and Sears theory, develop mathematical model for a wind turbine blade section with controllable leading-edge flap in turbulent wind, having 3 degrees of freedom: heave, surge and pitch.

2.2 Design robust optimal controller based on the above model using $H_2/H\infty$ control theory. This designed controller can achieve optimal fluctuating load reduction while guarantee enough robustness under disturbances and model errors because ultimately it is the wind turbine blades and not the mathematical model that must be stabilised.

2.3 Conduct simulation to evaluate the effectiveness of the above control system for fluctuating load reduction. If successful, this will motivate the research interest of smart rotor community towards to leading-edge flaps, and speed up the process of the smart rotor concept to be applied to commercial wind turbines.

3. Outcome and impact

The proposed work will lead to one conference paper. This research will help to achieve the aim of building substantially larger, more flexible and reliable wind turbines, reducing both construction and maintenance costs, thus making wind energy cheaper. Additionally the work has important spin-off applications for the fluid-dynamic control of other flexible structures which operate in a turbulent flow field, such as tidal stream turbines and High Altitude Long Endurance aircraft.

4. Follow-up PhD project

This miniproject can be extended to be a PhD project which will be collaborated with Prof. J.M.R. Graham at Imperial College London. Please contact Xiaowei.zhao@warwick.ac.uk for details.

5. References

[1] D.J.N. Limebeer, J.M.R. Graham and X. Zhao, Buffet suppression in long-span suspension bridges, *IFAC Annual Reviews in Control* **35** (2011), 235-246.

[2] X. Zhao, D.J.N. Limebeer, J.M.R. Graham and K. Gouder, Aerodynamic control of a sectional suspended-span bridge model, *Automatica,* under review.

[3] X. Zhao, K. Gouder, D.J.N. Limebeer and J.M.R. Graham, Buffet response and control of a suspension bridge section in a turbulent wind using leading- and trailing-edge flaps, to be submitted in March 2014 (experiment finished).