Dual pitch revisited: Overspeed avoidance by independent control of two blade sections

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Summary. Fast, coherent changes of wind speed during normal operation typically challenge the wind turbine's control system and can lead to ultimate loads and overspeed trips. In this work we demonstrate that independently controlling the aerodynamic forces along the blades' span can significantly reduce the risk of overspeeds in such situations. Specifically, we take up the concept of "dual pitch" where the blade is split up in an inner and an outer part with two independent pitch systems. We demonstrate that pitching the outer part towards feather and the inner part in the opposite direction (active stall) enables significant overspeed reduction without thrust force amplification. Simulations with a model of the IWT-7.5-164 reference turbine show that reductions of the maximum rotor speed of more than 10% of rated speed are feasible.

Background. In this work we consider the reduction in peak values of rotor speed and tower bending moment during a certain extreme operating condition above rated wind speed: a gust with rapidly increasing wind speed after it dropped shortly to near rated, similar to the well-known "Mexican Hat". This situation typically leads to high tower loads and potentially causes overspeed events. The large loads and rotor speeds are the result of the pitch controller acting to slow. During such an event there is a point in time at which

1. the rotor speed is low,
2. the blade pitch angle is small, and
3. the wind speed increases rapidly.

This leads to high rotor thrust force and aerodynamic torque. It seems reasonable to increase the pitching speed in order to mitigate the negative effects.

However, during the development of methods for mitigation strategies we found that on large-scale wind turbines the said operating condition can result in different aerodynamic conditions along the blade span: While the angles of attack of the outer blade sections stay in a normal range, those at the inner sections are significantly increased. Thus, the inner sections of the blade operate in stall conditions. From an overspeed prevention point of view this is beneficial since it causes a reduction of aerodynamic torque.

However, the contribution of the inner blade sections to the aerodynamic torque is increased if the full blade is pitched further towards feather with the goal of reducing the aerodynamic torque in an attempt to prevent overspeed. We found this effect to be a considerable. In our research project on control systems for the reduction of extreme loads of large-scale wind turbines we consider pitching the outer section of the blade independently from the inner section.[1] This provides the potential to improve the effectivity of the control system during the operating condition described above.

Approach. The blade is divided into two sections: the outer section from element 10 (blade tip) to element 6 and the inner section from element 5 to element 1 (blade root). Thus, the two sections may be pitched independently (see Figure 1).

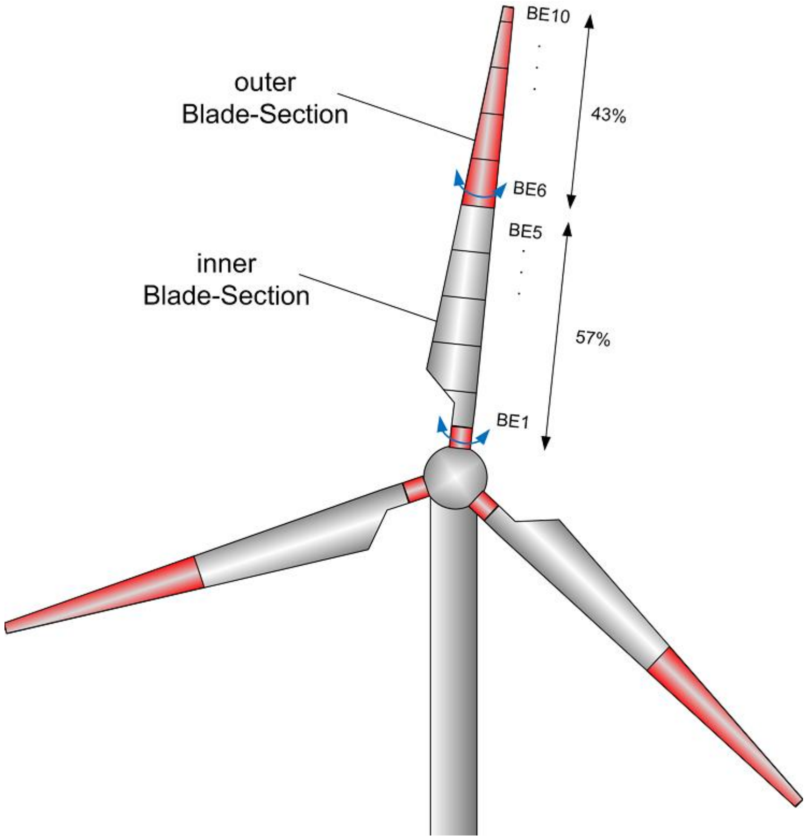

Figure 1: Division of blade sections on large-scale wind turbine for dual pitch

Three kinds of feed-forward pitch manoeuvres are being investigated to demonstrate the potential of the dual pitch approach during the operating condition described above and compared to the standard feedback control:

A. Standard feedback
B. Full Blade 3°/s: pitching the entire blade towards feather with a constant rate of 3 degrees per second
C. Outer section 3°/s: pitching only the outer blade section towards feather with a constant rate of 3 degrees per second

[1] This has also been investigated by van Engelen et al. in the framework of the so called "dual pitch" during the UpWind project [1], where the main reason for splitting the blades was to control thrust force and aerodynamic torque independently and reduce out-of-plane blade bending.

D. Inner section -3°/s, Outer section 3°/s: pitching the outer blade section towards feather with a constant rate of 3 degrees per second and counter-rotate the inner blade section towards stall

Prior to the investigated pitching manoeuvers, the extreme gust is detected and the need for control action is triggered. The algorithm facilitating detection and triggering are not considered in this paper.

The first eight seconds following the trigger instant are evaluated during the post-processing. The signals considered are

- the generator speed and
- the changes in aerodynamic moments of blade elements.

We are neglecting any effects on the structural dynamics of the blade at this point, such as changes in blade loads caused by sudden change in aerodynamic forces along the blade axis.

Numerical results. The approach deals with an extreme turbulence model (ETM) as defined in [2]. Simulations have been carried out with the IWES 7.5 MW reference wind turbine [3] using our in-house aero-servo-elastic code "WTsim" [4, 5].

Table 1 summarises the variations of the parameters resulting in four simulation runs. The first simulation contains a standard controller. The following three simulations are the feed-forward pitch manoeuvres mentioned above (Full Blade, Outer Section, Outer and Inner Section).

Table 1: Parameter variations of the numerical study.

mean wind speed at operating point[2]	{20}	m/s
extreme event detection time using standard controller	{78.58}	s
trigger point before extreme event is present	{6}	s
pitch rates of inner section	{feedback; 3; 0; -3}	°/s
Pitch rates of outer section	{feedback, 3; 3; 6}	°/s

Figure 2 shows the development of the generator speed beginning at the trigger point before the extreme event occurs at 78.58 s. The blue line represents the behaviour of the standard controller. The pitching of the full blade towards feather with a constant rate of 3 degrees per second and its influence on the generator speed is shown by the red line. A speed reduction of about 10 % is achieved. One would expect that this manoeuvre leads to the greatest reduction of the aerodynamic moment as well as generator speed. However, by pitching only the outer five blade elements, further reduction of generator speed is achieved (see orange line in Figure 2). Moreover, while counter-rotating the two blade sections, the reduction of generator speed is even greater. This is shown by the magenta line.

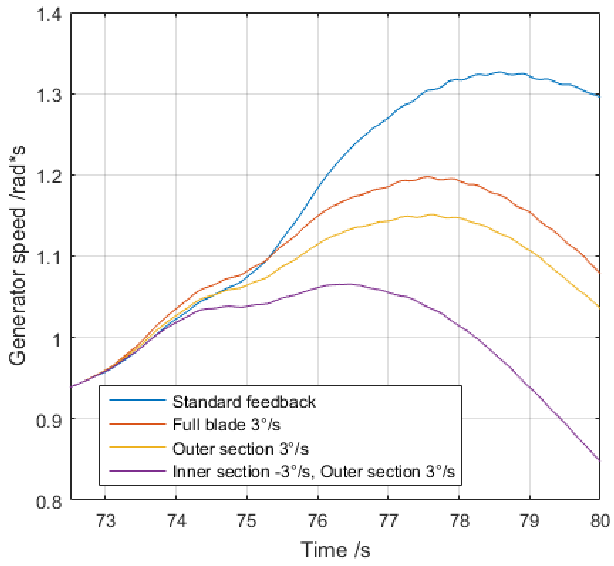

Figure 2: Generator speed during an extreme event using different strategies of section movements

In this context, Figure 3 shows the corresponding changes in aerodynamic forces. In regard to the standard feedback, the three pitching manoeuvres lead to a similar reduction of the aerodynamic moments at the outer blade section (BE10-BE6). This is comprehensible, because in all three cases the outer section makes the same rotation relative to the pitch axis.

When pitching the entire blade towards feather (Full Blade 3°/s), the changes of the aerodynamic moments at the inner blade section (BE5-BE1) are small compared to the standard controller. In this case, the generator speed reduction results mainly from the outer blade section.

A further reduction in aerodynamic moments is achieved by pitching only the outer blade section towards feather with a constant rate of 3 degrees per second (Outer section 3°/s). The inner section pitch remains fixed at the trigger point value. Thus, a fixed inner section pitch leads to improved aerodynamic moment reduction.

As a consequence, when pitching the outer blade section towards feather and counter-rotate the inner blade section towards stall (both with a constant pitch rate of 3 degrees per second), maximum generator speed reduction is achieved by a significant decrease in aerodynamic moments of the inner blade section.

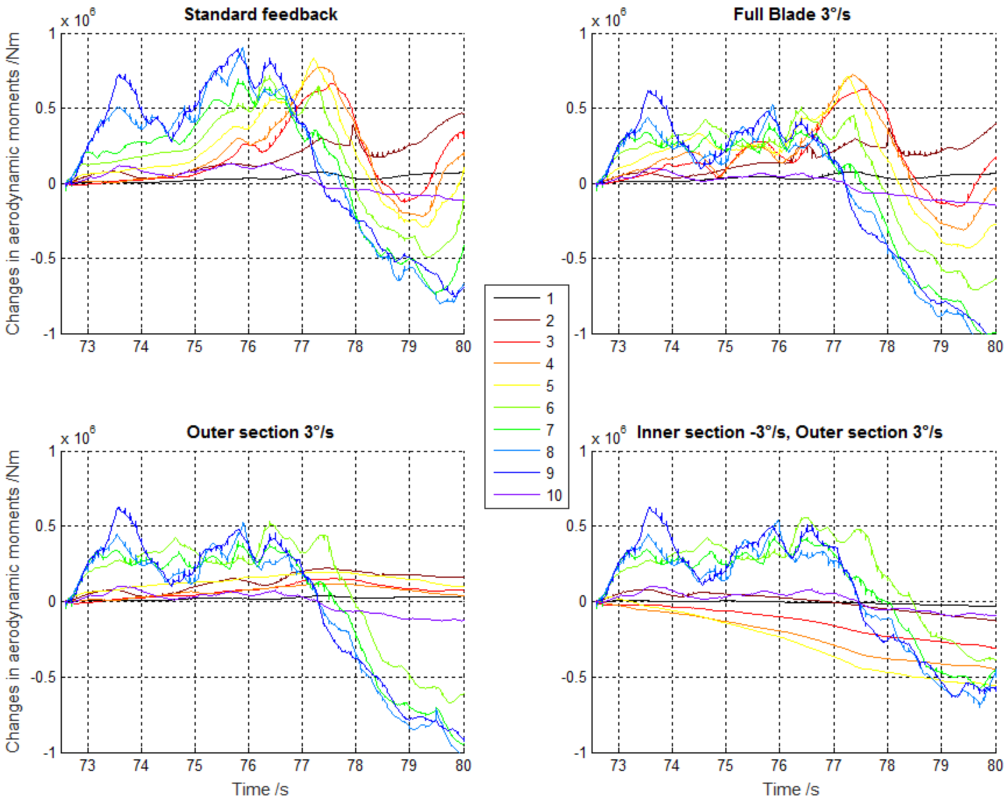

Figure 3: Changes in aerodynamic moments of each blade element during an extreme event using different strategies of section movements

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