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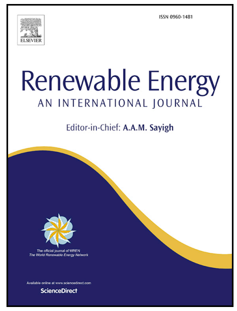

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Matched Pitch Rate Extensions to Dynamic Stall on Rotor Blades

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Abstract

Dynamic stall on both horizontal axis and vertical axis wind turbine blades is accompanied by simultaneous changes in pitch and surge, but this simultaneous effect has never been documented. Using a unique unsteady wind tunnel, synchronous oscillations in angle of attack and flow speed were considered on two prototypical wind turbine blades. At a steady freestream, the concept of matched pitch rate was observed to be valid for large positive and negative pitch angles. In the presence of an unsteady stream, matching the flow speed as well as the pitch angle and its time derivative during pitch-up produced excellent correspondence between lift, drag and moment coefficients throughout the entire dynamic stall event.

Keywords: dynamic stall, matched pitch rate, unsteady aerodynamics, wind turbine

1. Introduction

As the trend to increase the size of commercial wind turbines continues, the mechanical loads acting upon the rotor blades are becoming a key challenge. In addition to the cyclic gravitational loads, the combination of the earth's boundary layer, atmospheric turbulence, yaw misalignment and other factors leads to dynamic variations of the inflow conditions that translate to unsteady aerodynamic loads. In order to withstand the resulting fatigue stresses, a robust construction of the blades as well as other components such as the gearbox is essential.

The aerodynamic forces acting upon a given segment of a rotor blade exhibit particularly severe fluctuations when the boundary layer dynamically separates from the suction surface. This unsteady phenomenon referred to as dynamic stall is typically caused by a rapid change in inflow conditions such as a sudden increase in angle of attack. When the static stall angle α_s is exceeded, the boundary layer briefly remains attached and a dynamic lift overshoot occurs. The subsequent separation process is characterized by the shedding of the dynamic stall vortex (DSV), which is formed close to the leading-edge above the suction surface where it initially remains and grows in strength until its shedding into the wake triggers full boundary layer separation. The downstream convection of the DSV is accompanied by a sharp decrease of the pitching moment followed by a loss in lift. Although dynamic stall is generally accompanied by a change in flow speed, this is almost never reproduced in wind tunnels [1].

In this work, dynamic stall is experimentally investigated on two airfoil sections that are typical of stall regulated horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) respectively. Both turbine types are illustrated in Fig. 1. In an idealized sense, the rotor blades of HAWTs operate at a steady inflow which contributed to the predominant use of this turbine concept in large scale, commercial electricity generation. In practice, however, the inflow is often highly unsteady. When the incoming wind is not oriented perpendicular to the rotor disc (yaw error), the so-called advancing and retreating blade effect causes periodic fluctuations in angle of attack α and relative flow speed V_{rel} [2]. This can lead to dynamic stall particularly at high wind speeds and low tip speed ratios.

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