Morphing blades for unsteady load alleviation of wind and tidal turbines

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Abstract

A critical challenge for wind and tidal turbines is managing highly unsteady inflow due to the flow shear profile, turbulence and, for tidal devices, waves. This causes large variations in the magnitude and direction of hydrodynamic loading both temporally and spatially, across the rotor swept area. The fluctuating loads cause vibrations, which are transmitted to the rest of the turbine, causing fatigue and reducing reliability. Load variations also cause generator power output to fluctuate, reducing power quality and necessitating the use of expensive power electronics.
Offshore wind and tidal turbines are particularly affected. Offshore wind turbines are larger so experience greater temporal and spatial flow variation across the rotor and have more flexible blades, which increases aeroelastic coupling. Tidal turbines operate in a harsher environment than wind turbines; seawater is more than 800 times denser than air, wave loading adds further instability to the flow and cavitation may occur during stall.

To successfully alleviate unsteady loads, the response bandwidth must be twice that of the disturbance frequency. Wind turbulence occurs up to approximately 6 Hz, necessitating a bandwidth of 12 Hz. Traditional, full-blade pitch actuators only operate up to about 0.25 Hz and are typically underpowered, further limiting their effectiveness. Generator reaction torque, another traditional control parameter, has high bandwidth but is limited by its inherent lack of spatial discrimination.

Existing active control methods using small, low inertia surfaces, such as trailing edge flaps, are effective at unsteady load mitigation. However, they require power, electronics, hinges, bearings and mechanisms that are susceptible to debris and biofouling. Additional complexity poses a risk to reliability and increases O&M, a major driver for LCOE offshore, thereby discouraging the use of active control. Existing passive control methods predominantly rely on aeroelastic tailoring, such as bend-twist coupling, which respond too slowly to mitigate turbulence and only significantly affect loads on the outer section of the blade.

We propose a novel passive load-control system that is capable of turbulence rejection and is equally applicable to wind and tidal turbines, as well as aircraft. Our novel morphing blade has a flexible, variable geometry trailing edge that extends along the entire blade span. Its relatively lower inertia enables mitigation of high frequency load variations, previously only achievable through active control. Additionally, its spanwise tailoring allows loads to be cancelled along the entire blade, even at the root, producing a cleaner wake and improving

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farm efficiency.

We previously showed that the tailored morphing blade completely counteracts load fluctuations along the entire blade span. This prevents flow separation, lowering the time-averaged thrust, which simultaneously increases power output and quality.
In the current work, we experimentally test a prototype morphing blade for a tidal turbine in a combined wave-current flume and compare it to a solid blade. Both blades use the NACA 0012 profile, with the morphing blade having a sprung trailing edge flap. Tests are conducted on 2D blade sections that span the width of the flume. For these preliminary investigations, the blade kinematics are prescribed to mimic the deterministic hydrodynamic load oscillation experienced by a horizontal axis blade rotating through the flow shear profile in a real tidal current channel. Thus, the blade section is oscillated in pure heave in a uniform freestream flow. Hydrodynamic force and PIV analyses provide insight into the fluid-structure interaction and vortex dynamics of the novel blade.

Keywords: wind, tidal, unsteady load, morphing, passive, camber control