SAND2010-3276C

Passive Load Control for Large Wind Turbines

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Abstract

Wind energy research activities at Sandia National Laboratories focus on developing large rotors that are lighter and more cost-effective than those designed with current technologies. Because gravity scales as the cube of the blade length, gravity loads become a constraining design factor for very large blades. Efforts to passively reduce turbulent loading has shown significant potential to reduce blade weight and capture more energy. Research in passive load reduction for wind turbines began at Sandia in the late 1990's and has moved from analytical studies to blade applications. This paper discusses the test results of two Sandia prototype research blades that incorporate load reduction techniques. The TX-100 is a 9-m long blade that induces bend-twist coupling with the use of off-axis carbon in the skin. The STAR blade is a 27-m long blade that induces bend-twist coupling by sweeping the blade in a geometric fashion.

I. Introduction

The Wind Energy Department at Sandia National Laboratories (SNL) conducts research in several technology areas that provide innovations for large wind turbine rotors and blades. Innovations are targeted at lowering the cost-of-energy and developing increasingly more efficient rotors that are lighter, more reliable and able to capture additional energy. These goals can be met through a variety of technologies: advanced materials, designs that optimize both aerodynamic and structural performance, and load alleviation [1]. Passive load control is the subject of this paper as Sandia has been working in this area for over a decade now. Lowering loads to the blade in a passive manner (primarily in Region III) leads to either lighter blades or longer blades for the same turbine power rating. Lighter blades help reduce the rate of increase of gravity loads that come with the trend to go to larger and larger turbines. Longer blades for the same rating effectively "moves the power curve to the left" resulting in increased energy capture. The incorporation of bend-twist coupling into blades is the concept used to create the passive load control. The bend-twist coupling concept allows for more twist as the blade bends, which lowers the angle of attack and reduces loads; performance is maintained by adjusting the pitch schedule. This paper will review the SNL work that created the bend-twist coupling theory and discuss the test results of two prototype blades that incorporate coupling in two distinct ways. The TX-100, a 9-m long blade, uses off-axis materials, and the K&C STAR 27-m blade uses geometric sweep to create this coupling for reduction of loads in a passive manner.

II. Passive Load Control

Previous work has shown the potential for modifying blade designs to incorporate bend-twist coupling in ways that passively reduce loads in high winds [2-7]. For passive load control using bend-twist coupling, blades can be designed in a least two different ways. Geometric-based coupling uses sweep along the blade to create a moment that induces twist [8]. A second method, material-based coupling, aligns the primary load-carrying spanwise fibers in an off-axis manner by about 20 degrees, so as the blade bends, it twists more than normal allowing loads to be relieved. In both cases, the idea is to effectively create more coupling between the flap and twist motions of the blade. Necessary design goals are to maintain flapwise strength and maximum tip deflection.

> Bend-twist coupling in wind turbine blades can reduce both fatigue and extreme operating loads, especially when applied in conjunction with a pitch-controlled rotor. This type of coupling has

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[*] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.