Aero-Structural Design Optimization of Composite Wind Turbine Blade

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Abstract

A multidisciplinary design optimization (MDO) process is defined for a SERI-8 wind turbine blade to optimize its aerodynamic and structural performance. The objective behind this research is to develop a fluid-structural interaction (FSI) system for SERI-8 composite blade to maximize aerodynamic efficiency and structural robustness while reducing blade mass and cost. In the previous research, a MDO process of a composite wind turbine blade has been pioneered as effective process to develop structurally optimized blade design. A multidisciplinary design optimization process is defined in conjunction with structural and aerodynamic performance of the blade. The composite wind turbine blade MDO is divided into three steps and the design variables considered are related to the shape parameters, twist distributions, pitch angle and the relative thickness based on number of composite layers. The constraints are tip deformations and allowable stresses. The results of the first step are aerodynamically optimal angle of attack of airfoils for the blade cross-sections along the blade span wise direction, and the pressure distribution along the blade at maximum lift and wind conditions. Airfoil performance is predicted with XFOIL/Qblade, while CFD analysis is performed by CFX software. The second step yields optimal material, composite layup distribution of the blade and involves structural analysis for transferred pressure load from CFD analysis. A parameterized finite element model of the blade is created using ANSYS design modeler/meshing and ACP composite prepost is used to define composite layups of the blade. At the last step, the results of the CFD and the structural analysis are transferred to ANSYS design explorer; accompanied by the cost estimation for the optimization process. The number of design of experiments (DOEs) is defined by Central Composite Design-G optimality method and response surface is created. With the consideration of maximum power output and minimum weight, an optimal blade design is found within the pre-defined design variable parameters and structural constraints. Sensitivity analysis is also performed to observe the impact of input parameters on output parameters for enhanced control of the MDO process.

Keywords: Aero-Structural Optimization, Wind Turbine, Composite Structures, Multi-Objective design Optimization, Fluid Structure Interaction, Computational Fluid Dynamics.

1. Introduction

Wind turbines have become an economically competitive form of clean and renewable power generation. In the United States and abroad, the wind turbine blades continuing to be the target of technological improvements by the use of highly effective and productive design, materials, analysis, manufacturing and testing. Wind energy is a low density source of power [1]. To make wind power economically feasible, it is important to maximize the efficiency of converting wind energy into mechanical energy. Among the different aspects involved, rotor aerodynamics is a key determinant for achieving this goal. There is a tradeoff between aerodynamic efficiency (thin airfoil) and structural efficiency (thick airfoil) both of which have a strong effect on the cost of electricity generated. The design process for optimum design therefore requires determining the optimum thickness distribution by finding the effect of blade shape and varying thickness on both the power output and the structural weight.
Due to the development of computer aided design tools, the design, analyses and manufacturing of wind turbine blades were made very cost effective and feasible. Aerodynamics performance of wind turbine blades can be analyzed using computational fluid dynamics (CFD).The finite element method (FEM) can be used for the blade