Dealing with the curse of dimensionality in the blade multi-disciplinar optimization

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Abstract

The blade design conceived as a holistic multi-disciplinar optimization that involves different engineering fields (aerodynamic, elasticity, control, loads) presents important challenges due to the high number of design variables and the expensive computational cost to calculate the objective function that can make unaffordable the optimization. To overcome this problem, two aspects of the optimization problem definition are studied: the identification of the significant design variables by means of global sensitivity methods and the calculation of the fatigue damage equivalents load in the frequency domain which provides a great advantage in terms of computational cost with respect to standard time domain methods.

Keywords: Blades, optimization, multi-disciplinar, sensitivity, Latin Hyper Cube (LHS), fatigue, Dirlik, linearized model.

1. Introduction

With the increasing size of wind turbine blades over the last few years, designing an efficient blade is becoming a fundamental task for creating a wind turbine with a low cost of energy (COE). The traditional methodology of dividing the blade design into separate problems—airfoil geometry, spanwise distributions, structural layout design and loads calculation verification—is evolving into a multi-disciplinary design optimization that interconnects different disciplines, such as aerodynamics, elasticity, loads and control [1]. Recent research has proven that sequential aero/structural optimization provides significantly suboptimal solutions compared to integrated aero-structural metrics [2]. The curse of dimensionality, applied for optimization problems is referred to the complexity that arises when the number of design variables is increased [3]. To deal with this phenomenon two approaches are explained in this paper:

The first part of the paper (section 2) summarizes the identification of important design variables by means of Latin Hypercube Sampling and global sensitivity analysis [4] [5].

The second part of the paper (section 3) is focused in the calculation of the fatigue equivalent load. In contrast to the expensive time domain calculation, frequency domain fatigue method is proposed to be included in the optimization. The method provides a great advantage in computational cost, although the estimation is not satisfactory for some type of loads [6].

2. Global sensitivity analysis of blade design variables.

For the sensitivity analysis, a MATLAB based code is developed to calculate the relevant wind turbine outputs: annual energy production (AEP), blade deflections, loads, overall sound power level.

The Latin Hypercube Sampling (LHS) is an appropriate tool to generate input data for simulation model sensitivity analyses. It covers the parameter space efficiently with a reduced number of observations and allowing a specific sampling probability distribution. Multi-variable linear regression techniques are used to identify the relevant variables by comparing the standardised regression coefficients for each design variables [5]. Moreover, the linear model serves as meta-model for the optimization problem that substitutes expensive simulations.

3. Fatigue calculation in the frequency domain

The frequency domain fatigue calculation method is divided into two parts. Firstly, an aero-elastic code serves to make the wind turbine non-linear equations of motion linear and to obtain the state of spaces matrices. From these matrices, a frequency response function (FRF) is obtained. This FRF serves to relate the inputs of the wind turbine in the frequency domain with a specific turbine load. Next, the power spectral density (PSD) of this load is calculated. Secondly, based on the PSD, the well-known Dirlik equations are applied, obtaining a distribution of load cycles in the function of ranges. Then, the damage equivalent load is obtained by applying the Miner rule.

This method is compared with the standard time domain calculation demonstrating that provides a great advantage in time. However the accuracy is not satisfactory for in-plane periodic loading [6].

4. Conclusions

The use of a multi-disciplinar calculation tool that calculates the wind turbine outputs as function of the blade geometric and structural design variables in conjunction with global sensitivity analyses permits the identification of the relevant blade design variables. Besides, the non-important variables can be removed from the optimization without losing of benefit [4].

In addition, the calculation of the fatigue damage in the frequency domain permits its inclusion in the optimization problem without a dramatic increase in the computational cost. The method is accurate for the loads with stochastic nature [6].

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