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Load Calculations for Different Blade Geometry Using Response Surface Methodology

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1 Introduction

Response surface is a high dimensional polynomial surface that represents a relation between set of inputs to outputs [1]. It generates a synthetic data that can be used explore all the defined design space with low computational cost. Response surface methodology (RSM) is proposed to be applied on the calculation of aerodynamic loads of NREL 5MW wind turbine as a function of blade geometry.

2 Methodology

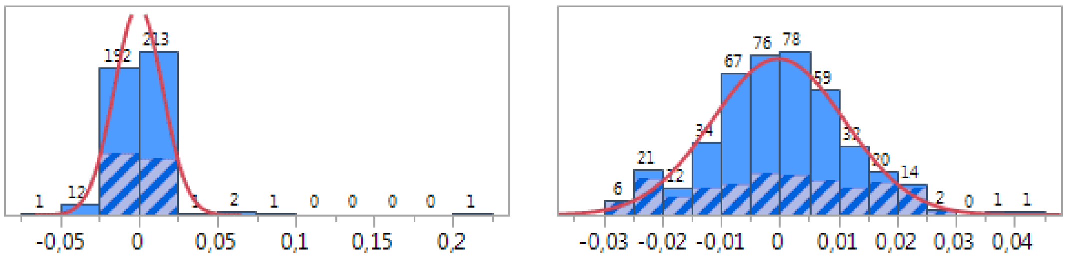
Response surface methodology is previously used in wind energy applications to calculate mechanical power in terms of tip speed ratio, pitch angle and the aerodynamic power coefficient and to identify the relation between the wind field parameters and the aerodynamic loads on the rotor [2, 3].

In this study aerodynamic loads are calculated as a function of blade geometry which is defined as chord distribution, twist distribution and thickness-to-chord ratio distribution for NREL 5MW wind turbine. Each of these distributions are defined at 19 parameters along the blade span hence total of 57 design parameters are used as a start. These parameters are disturbed 10 % from their baseline values. As aerodynamic loads flapping moment and torque are investigated.

Design parameters that have high influence on the loads are selected by a screening process in order to decrease the number of design parameters. For 57 design parameters, a two-level fractional factorial design is used as design of experiment (DoE) methodology and 128 experiment points are created. One center point is added to simulate quadratic effects resulting in 129 points to be simulated to examine the significance of blade geometry for the loads. JMP Statistical Analysis Software is used for DoE creation and sensitivity analysis and FAST code is used to calculate loads for different blade geometries [4].

The relative importance of a design parameter on the response can be investigated using their t-ratio value, which represents the ratio of estimate to its standard error [5]. Higher value for the t-ratio for a certain design parameter indicates that that design parameter has relatively higher influence on the response. JMP software creates a response surface for maximum 8 parameters and with this design parameters selection chord parameters have the highest 8 t-ratio values. In order to see some twist effects on the loads, design parameters are rearrenged. Some chord and twist points are removed along the span and they are asumed to be changing linear depending on the defined design parameters. Hence parameter number is desreased to 48. The screening process is repeated for new design parameter configuration and 8 most important parameters are chosen, 5 chord parameters and 3 twist parameters.

Central composite design is used this time to create a new DoE with 273 experiments in order to fit a responce surface that calculates loads as a function of chord and twist parameters. Selected 8 parameters are changed accordingly to the DoE table and other parameters are kept same with the baseline since their effects on the loads are negligible. Least square method is used to fit a second order polynomial as a response surface for flapping moment and torque outputs.



(a) Flapping Moment

(b) Torque

Figure 1: MFE & MRE Distribution

Model fit error (MFE) which is the relative error of the predicted value provided by the response surface to the actual value is calculated to check the wellness of the fit [6]. It is seen that MFE has a distribution with a mean 0 and standard deviation smaller than 1 for both load outputs that satisfies the main assumption of the linear regression analysis [7].

Response surface works fine for the DoE points that are used to fit the model but accuracy of the model other than these points should be examined. For this purpose model representation error (MRE) is calculated. 150 random points are created inside the design space and simulation results at these points are compared with the response surface results. Notice that these random points are not used while fitting the response surface. When MRE distribution is examined, it is seen that is has also a distribution with mean 0 and standard deviation less than 1 for both loads. Figure 1 shows MFE & MRE distribution for flapping moment and torque. The dashed area shows the MRE distribution and the numbers above the bars show the count number of cases for that error.

3 Conclusion

Application of response surface methodology to load calculations enables us to examine different blade geometries with lower computational cost. In this study, flapping moment and torque outputs of NREL 5MW wind turbine are calculated as a second order polynomial of blade geometry which is defined by 5 chord, 3 twist parameters along the blade span.

Acknowledgements

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