15th EAWE PhD Seminar on Wind Energy
29–31 October 2019
Centrale Nantes, France

Sensitivity of load application methods used for wind turbine blade design

W J Veloz Parra[a], Y Aoues[a], and D Lemosse[a]

[a]Normandie Univ, INSA Rouen Normandie, LMN, Rouen, France, 685 avenue de l'université BP 08, 76800 Saint Etienne de Rouvray Cedex - France.

E-mail: wilson.veloz_parra@insa-rouen.fr

Keywords: Sensitivity Analysis, Load Application, Wind Turbine Blade, Shell Finite Element Model, Composite Mateial.

Introduction

Wind turbine blades are subjected to wind pressure distribution that depends on the external environment conditions and inertial loads from their rotational velocity, acceleration and the turbine control (start-up, power production, normal shutdown, emergency shutdown, etc). To simulate the effect of these loads in the wind turbine blade some numerical tools are used. They are based on multi-physics simulation joining aerodynamics, hydrodynamics, control, and electrical system and structural dynamics models. That enables a coupled nonlinear aero-hydro-servo-elastic simulation in the time domain using a multi-body 1D beam finite element model (FEM). However, when we are interested in a detailed analysis of the blade, a shell FEM with applied 3D loads must be used to obtain buckling and/or fatigue analysis.

Therefore, the loads evaluated by 1D beam FEM simulations are transformed into an equivalent 3D pressure distributed loads for the shell FEM. Depending on how the loads are applied to the shell model, some simple methods can introduce numerical stress concentration. But other, more complex methods can have a better distribution of the stress. In the literature, it can be founded several ways to transfer the loads, called load application method (LAM), changing the way, how the loads are applied in the shell FEM. These methods are classified by Caous [1] depending on the physical way in which the loads are applied.

Their objective is to replicate the same behavior as the one produced by the 1D beam simulations. Each of these LAM differs in the stress distribution and displacement response of the blade, the first 2 groups induce stress concentration but the computational time is less than the last 2 groups in which, no stress concentration is induced, however, their computation cost increases to 6 times. In the context of the structural reliability analysis, optimization of the wind turbine blade or surrogate model creation, the suitable method should be selected concerning his sensitivity, produced by uncertain in the LAM input parameters. This study present, a sensitivity analysis using a screening method of different LAM in a wind turbine blade shell FEM, involving uncertain input parameters as applied loads and material properties regarding as output the tip displacement and the stress at one spot of the blade.

Blade model and evaluation methodology

The wind turbine blade taken as reference was the DTU 10MW [2], but the material distribution was simplified to define the thickness as an input variable. In the span-wise direction, the blade was divided into 3 groups (up, middle and down) and the airfoil cross-section was redefined as 3 groups: Lead Panel (Nose and leading panels), Shear Webs (All shear webs) and Tail Panel (the rest of the groups), were each group have the same distribution of composite materials giving a total of 28 input variables for material property. Also, the material used was changed from the original ones used by DTU 10MW blade, in this case, is used QQ1 and P2B extracted from SNL/MSU/DOE composite material database [3].

To evaluate the sensitive effect of different LAM, the forces applied in the shell FEM are selected as input variables. In this case, only 10 nodes can be defined in the 1D multi-physics simulation tool giving 6 variables (3 forces and 3 moments) per each node (60 variables in total) and then these are applied in 10 sections defined in 10 locations on the shell FEM. Only two LAM are used: one from the first group, applying the loads to the sections defined as rigid body elements [4], and from the second group, applying the loads in 4 nodes [1].

The Morris method [5] is used to evaluate the sensitivity in 2 different outputs, first the tip displacement of the blade and second the stress at one point of the blade located in the cap section (selected by the authors). Both sensitivity analyses are evaluated in both LAM to compare their sensitive effects. Different experiments are defined changing the number of inputs variables, first, all variables (material thicknesses and loads) are used, and then, only the load variables of each LAM. These experiments are performed in both outputs variables, and also, for each LAM selected in this study.

Results and discutions

The result obtained shows for both outputs and both groups of variables there is not a non-linear effect in the inputs variables, only linear and neglected effect. In the case of tip displacement, using all inputs variables, LAM 4 Nodes is the most sensitive method showing a maximum linear effect in the material thickness but also shows a linear effect in the forces and moment applied around 0.4 - 0.6 normalized μ^*. In the same experiment but for LAM RBE the material thicknesses are the most sensible variables.

In the 2nd case when the output is the stress, using all input variables, LAM 4 nodes is the most sensitive method as well, also having a maximum linear effect in the material thickness but in this case the forces and moments have a closer linear effect from the maximum around 0.8 - 0.9 normalized μ^*. On the other hand, LAM RBE has similar behavior, the material thickness is the most sensitive variables.

In order to compare the two LAM, only their inputs variables are evaluated and for both outputs, LAM 4 Nodes has the higher sensitivity always having a linear effect in the outputs, LAM RBE has also a linear effect but his maximum sensitive value for tip displacement output is around 0.3 - 0.4 and for stress output is around 0.1 normalized μ^*. Resulting as the less sensible of all the methods evaluated for both outputs and all selected group of inputs variables.

Acknowledgements

This research was supported by The Ministry of Higher Education, Science and Technology and scholarship program Caliope.

References

[1] Caous D, Lavauzelle N, Valette J and Wahl J C 2018 *Wind Engineering*

[2] Bak C, Zahle F, Bitsche R, Kim T, Yde A, Henriksen L C, Hansen M H, Blasques J P A A, Gaunaa M and Natarajan A 2013 *Danish Wind Power Research 2013*

[3] Mandell J and Samborsky D 2016 *Montana State University, Bozeman*

[4] Griffith D T and Ashwill T D 2011 *Sandia National Laboratories, Albuquerque, Report No. SAND2011-3779* 67

[5] Morris M D 1991 *Technometrics* **33** 161–174

.