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Fluid Structure Interaction Modelling of A Novel 10MW Vertical-Axis Wind Turbine Rotor Based on Computational Fluid Dynamics and Finite Element Analysis

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Abstract

Large wind turbines are commonly required to be designed to meet international safety standard IEC 61400-1. According to IEC 61400-1, aeroelastic effects, which are caused by FSI (fluid structure interaction), should be taken into account in the design of the turbine. Therefore, FSI modelling of wind turbine rotors has become an important part in the development of large wind turbines. In this work, an one-way FSI model for VAWT (vertical-axis wind turbine) rotors at full scale is established. The aerodynamic loads are obtained using CFD (computational fluid dynamics), and the rotor structural responses are determined using FEA (finite element analysis). The coupling of CFD and FEA is based on the one-way coupling method, in which the aerodynamic loads obtained from CFD modelling are mapped to FEA modelling as load boundary conditions. The one-way FSI model was applied to the FSI modelling of NOVA 10MW wind turbine rotor, which is a novel large-scale VAWT rotor. The rotor pressure distributions, stress distributions and deformations are investigated based on the one-way FSI modelling.

Introduction

Background

According to IEC 61400-1 [1], aeroelastic effects, which are caused by FSI (fluid structure interaction), should be taken into account in the design of large-scale wind turbines (e.g. NOVA 10MW VAWT [2] depicted in Fig. 1). Therefore, FSI modelling of wind turbine rotors has become an important part in the development of large wind turbines.

Figure 1. Concept of NOVA 10MW VAWT [2]

Motivation

FSI modelling requires an aerodynamic part to calculate the wind loads and a structural part to determine structural dynamic responses. For the aerodynamic part, CFD (computational fluid dynamics) has been receiving great attention in recent years due to the rapid advancement of computer technology. For the structural part, FEA (finite element analysis) is considered to be the most accurate method among the existing structural models [3]. One challenge facing wind turbine designers today is to couple CFD and FEA for FSI modelling.

Aims and objectives

This study aims to investigate aeroelastic behaviour of large-scale VAWT rotors based on one-way FSI modelling. This is achieved through the realisation of the following objectives:

- To establish both CFD and FEA models of VAWT rotors
- To establish a one-way FSI model of VAWT rotors through one-way coupling of CFD and FEA
- To apply the established one-way FSI model to the simulation of the NOVA 10MW VAWT rotor in a parked condition, under a 50-year extreme wind condition

Methods

Wind Turbine Rotor Model

The wind turbine rotor model used in this study is the NOVA 10MW VAWT rotor [2], a 2-bladed novel VAWT rotor combining sails and V-shape arms. The aerodynamic profile of the rotor is presented in Table 1, and its 3D geometry is depicted in Fig. 2.

Table 1. Aerodynamic profile of NOVA 10MW VAWT rotor

	Length (m)	Chord (m)	Root profile	Tip profile
Arm	143.0	8	NACA0025	NACA0018
Upper sail	36.8	11	NACA0015	NACA0012
Lower sail	55.2	11	NACA0015	NACA0012

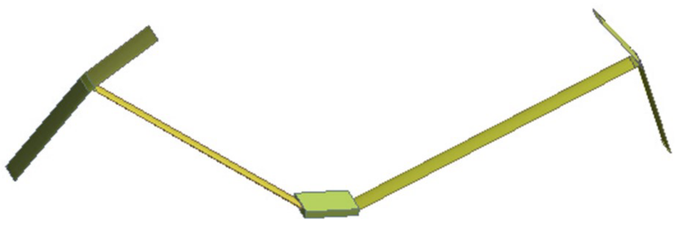

Figure 2. 3D geometry of NOVA 10MW VAWT rotor

CFD Modelling

The computational domain and mesh used in CFD modelling are illustrated in Figs. 3 and 4, respectively. In this study, K-Omega SST turbulence model is used.

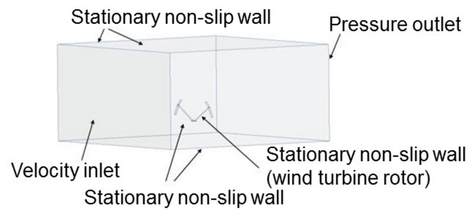

Figure 3. Computational domain

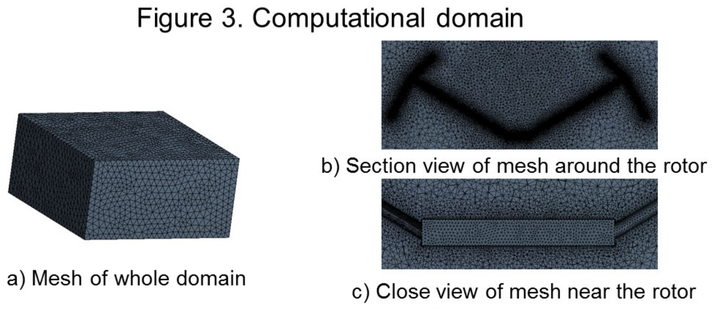

Figure 4. CFD mesh

FEA Modelling

The blade structure is meshed with structured mesh, as depicted in Fig. 5. The blade is made of composite materials, and material thickness distributions are presented in Fig. 6.

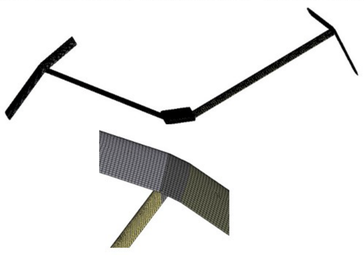

Figure 5. FEA mesh

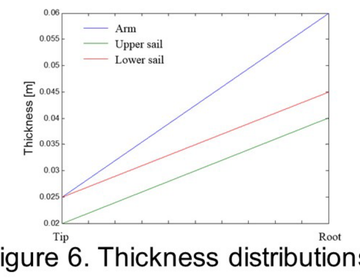

Figure 6. Thickness distributions

One-way FSI Coupling

The schematic of one-way FSI coupling is presented in Fig. 7.

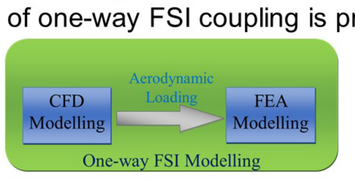

Figure 7. Schematic of one-way FSI modelling

Results and Discussions

Pressure distributions

Based on one-way FSI modelling, the pressure distributions, deformations and stress distributions of the NOVA 10MW VAWT rotor are examined. In this case, the wind speed and rotor rotational speed are 70m/s and 0rpm, respectively. The pressure distributions on the rotor are presented in Fig. 8.

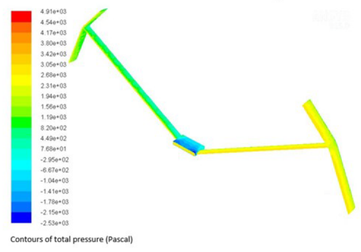

Figure 8. Pressure distribution on the rotor

As can been seen from Fig. 8, the pressure in front of the rotor is higher than the pressure behind the rotor, producing thrust forces on the rotor.

Rotor deformations

The rotor deformations are presented in Fig. 9.

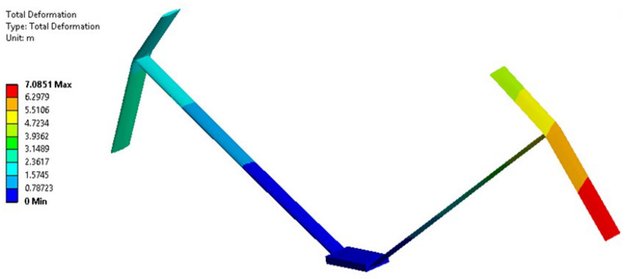

Figure 9. Rotor deformations

From Fig. 9 we can see that the maximum rotor deformation is about 7.09m, observing at the lower sail tip.

Stress distributions

The normal stress distributions within the rotor structure are presented in Fig. 10.

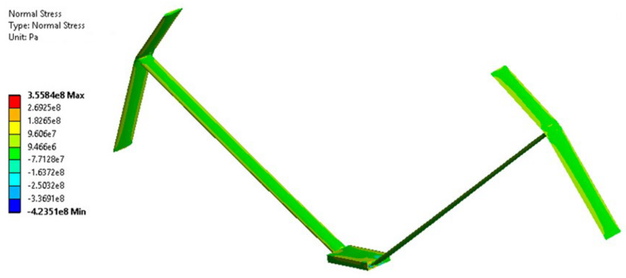

Figure 10. Normal stress distributions

As can be seen from Fig. 10, the maximum stress (positive normal stress) and maximum compression stress (negative normal stress) are 355.84MPa and 423.51MPa, respectively, which are within the allowable stresses.

Conclusions

In this study, an FSI (fluid structure interaction) model for VAWT (vertical-axis wind turbine) rotors has been developed by coupling CFD (computational fluid dynamics) and FEA (finite element analysis). The coupling method is based on a one-way coupling, in which the aerodynamic loads obtained from CFD modelling are mapped to FEA modelling as load boundary conditions. The FSI model has been applied to the NOVA 10MW VAWT rotor, a novel large-scale VAWT rotor. The pressure distributions, stress distributions and deformations of the NOVA 10MW VAWT rotor in a parked condition, under a 50-year extreme wind condition (70m/s), have been examined based on the one-way FSI modelling.

Acknowledgement

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References

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