Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 137 (2017) 282–290

Energy Procedia

www.elsevier.com/locate/procedia

14th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2017, 18-20 January 2017, Trondheim, Norway

A comparison of two fully coupled codes for integrated dynamic analysis of floating vertical axis wind turbines

Boy Koppenol[a], Zhengshun Cheng[b,c,*], Zhen Gao[c], Carlos Simão Ferreira[d], Torgeir Moan[c]

[a]*Ventolines BV, Duit 15, Emmeloord 8305BB, The Netherlands*
[b]*State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China*
[c]*Department of Marine Technology, AMOS and CeSOS, Norwegian University of Science and Technology (NTNU), Trondheim, Norway*
[d]*Faculty of Aerospace Engineering, Delft University of Technology (TU Delft), Delft, The Netherlands*

Abstract

This paper presents a comparison of two state-of-the-art codes that are capable of modelling floating vertical axis wind turbines (VAWTs) in fully coupled time-domain simulations, being the HAWC2 by DTU and the SIMO-RIFLEX-AC code by NTNU/MARINTEK. The comparative study focusses on the way aerodynamics, hydrodynamics and structural dynamics are treated for DeepWind's 5MW Darrieus rotor mounted on a modified OC3 spar platform. The relevant modelling differences are described, followed by an introduction to the spar VAWT concept and selected load cases. Isolation of the aerodynamic model is achieved using an equivalent rigid land-based VAWT in steady wind-only environments. The added complexity in SIMO-RIFLEX-AC's aerodynamic model has shown to increase aerodynamic torque at tip-speed ratios above 2.5. Differences in the hydrodynamic and structural models were brought forward through fully coupled analyses in turbulent wind and irregular wave climates. It is found that the simplified mooring system in HAWC2 introduces a 2P yaw response (1P in SIMO-RIFLEX-AC), stronger motion coupling in surge-heave and a largely reduced mooring line tension since the dynamics of mooring lines are not considered. Indications are given that a higher tower mode is excited by 4P aerodynamic loading; an effect that is significantly stronger in HAWC2.

Peer-review under responsibility of SINTEF Energi AS.

Keywords: floating vertical axis wind turbine; code-to-code comparison; fully coupled simulations

* Corresponding author. Tel.: +47-73596004; fax: +47-73595528.
E-mail address: zhengshun.cheng@ntnu.no

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of SINTEF Energi AS.
10.1016/j.egypro.2017.10.352

1. Introduction

An ever-increasing demand for electricity pushes the wind energy industry to deep waters that favour floating concepts. Floating horizontal axis wind turbines (HAWTs) are facing the challenges of high cost of energy; as an alternative, floating vertical axis wind turbines (VAWTs) have the potential to reduce the cost of energy and are thus of great interest. The VAWT was popular in North-America during the 1970s and 1980s, in this period considerable efforts were made to develop the Darrieus rotor [1]. Now, interest in floating VAWTs emerges for its simple design, low center of gravity and independence to wind direction. Potential benefits are reduced installation and O&M costs, blade manufacturing through the cost-effective pultrusion technique and possibly increased power efficiency [2].

In contrast with the conventional HAWT, the vertical axis rotor has a three dimensional swept volume that extends in the streamwise direction as well, which makes that a blade crosses the incoming wind flow in both the upstream- and downstream rotor half. The supporting platform should provide sufficient buoyancy and stability, which leads to a large structure with significant contribution from hydrodynamics. The mooring system is for station keeping and acts as a relatively soft spring compared to structural stiffness. Whilst our understanding of hydrodynamics and structural dynamics is fairly developed, VAWT aerodynamics is complex and introduces challenges with respect to load prediction. The floating VAWT system is highly dynamic and requires a fully coupled aero-hydro-servo-elastic simulation tool for accurate analysis. Presently only several publicly available codes have this capability, amongst them are the HAWC2 by DTU [3] and the SIMO-RIFLEX-AC code by NTNU/MARINTEK [4] that both account for aerodynamics through the Actuator Cylinder (AC) flow theory [5].

The work in this paper consists of a code-to-code comparison between SIMO-RIFLEX-AC and HAWC2 and is split to three parts: (1) demonstrating the general impact of dynamic stall, (2) illustrating the effect of different implementations of the AC flow theory and (3) presenting code-to-code differences in the dynamic response of a spar VAWT modelled in unsteady environments.

2. Numerical simulation tools

2.1. Aerodynamics

The aerodynamic loads are calculated using the AC flow model originally developed by Madsen [5]. A set of stacked cylinders is used to build the swept volume of the VAWT rotor. For numerical implementation Madsen has suggested a modified linear solution to solve the 2D flow problem of the individual cylinders. The solution that is implemented in HAWC2 contains an additional correction factor k_a for the induced velocities, as proposed by Madsen et al. [6]. Cheng et al. [7] further developed the model such that it accounts for the tangential loading term, inclination of blade elements and an additional correction to the induced velocities at higher tip-speed ratios. These developments are implemented in the aerodynamic model of SIMO-RIFLEX-AC. Hence the two codes correct the induced velocity differently, as highlighted by Fig. 1.

Dynamic stall is a phenomenon that occurs when the flow separates from the surface of the blade. For a VAWT it is likely to occur at low tip-speed ratios where the angle of attack changes more rapidly. Research has shown that it is essential to include the effect of dynamic stall for a more accurate prediction of the aerodynamic loads [8]. Due to its significance and hence sensitivity, it is chosen to match SIMO-RIFLEX-AC's dynamic stall model with the Stig Øye dynamic stall model implemented in HAWC2.

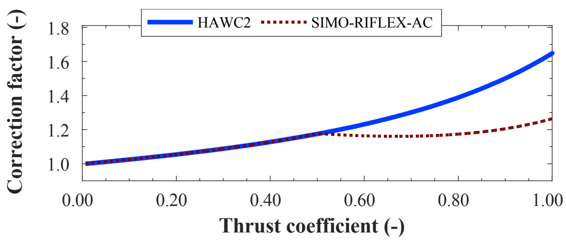

Fig. 1. Correction factor k_a in the modified linear solutions of the AC flow model.