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Dynamic analysis of a floating vertical axis wind turbine under emergency shutdown using hydrodynamic brake

K. Wang[1,2], M.O.L. Hansen[2,3] and T. Moan[1,2]

[1] NOWITECH, Norwegian University of Science and Technology, 7491 Trondheim, Norway
[2] Centre for Ships and Ocean Structures, Norwegian University of Science and Technology, 7491 Trondheim, Norway
[3] DTU Wind Energy, Department of Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark

Abstract

Emergency shutdown is always a challenge for an operating vertical axis wind turbine. A 5-MW vertical axis wind turbine with a Darrieus rotor mounted on a semi-submersible support structure was examined in this study. Coupled non-linear aero-hydro-servo-elastic simulations of the floating vertical axis wind turbine were carried out for emergency shutdown cases over a range of environmental conditions based on correlated wind and wave data. When generator failure happens, a brake should be applied to stop the acceleration of the rotor to prevent the rotor from overspeeding and subsequent disaster. In addition to the traditional mechanical brake, a novel hydrodynamic brake was presented to apply to the shutdown case. The effects of the hydrodynamic brake on the platform motions and structural loads under normal operating conditions and during the emergency shutdown events were evaluated. The use of both the hydrodynamic brake and mechanical brake was also investigated. The application of the hydrodynamic brake is expected to be efficient for rotor shutdown and for reducing the platform motions and structural loads.

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Keywords: Emergency shutdown; Floating vertical axis wind turbine; Platform motion; Hydrodynamic brake

1. Introduction

As wind turbines continue to extend to deep waters, different platforms are used as the floating support structures, such as spar, semi-submersible and TLP. Most studies in this field have focused on the design, structural integrity, platform motion and installation of floating horizontal axis wind turbines (FHAWTs) to better understand the performance of different concepts and provide a basis for detailed structural design. However, different concepts for floating vertical axis wind turbines (FVAWTs) have also been presented, including the DeepWind [1-3], VertiWind [4] and Aerogenerator X concepts [5], to evaluate their economic potential and technical feasibility. A novel concept combining the DeepWind 5-MW rotor [6] and DeepCwind floater of the OC4 project [7] has also been proposed, and a coupled non-linear aero-hydro-servo-elastic model for analyzing this concept has been established and accordingly verified [8].

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Many different challenges arise when FVAWTs operate under various wave and wind environmental conditions. Under normal operating conditions, the rotor can experience aerodynamic loads with continuous variation contributed by the azimuthal position and turbulent wind. Considerable forces acting on the rotor with fixed blades can be produced in stormy weather at increased rotational speed. The blades may also be deformed or broken, and the tower could collapse in more severe cases. Thus, determining how to initiate the emergency shutdown of a wind turbine is one of the most important concerns. The blade pitch mechanism is not applied in VAWTs with a Darrieus rotor, unlike in HAWTs, and the mechanical brake is installed in a standard manner. Experience has shown that aerobrakes also need to be installed to keep the rotational speed down in emergency situations when the generator torque is lost due to grid loss and the mechanical brake fails. The mechanical brake usually acts as a parking brake to stop the machine for maintenance purposes, therefore, aerodynamic braking is used to decelerate the rotor firstly and then the mechanical brake torque can be quite low. Although the mechanical brake is also used to bring the rotor to a standstill during high wind shutdowns for the majority of HAWTs, it is not easily applied for large scale VAWTs. Spoilers, an efficient and simple type of aerobrakes, are plates used to increase aerodynamic drag. However, the spoilers are integrated with blades, and their efficiency is determined by involving aerodynamic calculation of the blades together.

The current work presents a novel concept for a hydrodynamic brake that is installed at the end of the extended shaft of a vertical axis wind turbine through the centre column of the floater. The studied FVAWT has a 5-MW Darrieus rotor mounted on a semi-submersible support structure. The global motion and dynamic structural response of the FVAWT are calculated for the case in which the hydrodynamic brake is activated during emergency shutdown.

2. Methodology

2.1. Floating Wind Turbine Model

The FVAWT considered in this study is composed of a 5-MW Darrieus rotor, a semi-submersible and three catenary mooring lines. The rotor is located on a main column as shown in Fig. 1a. There are three offset columns with pontoons around the main column. Each catenary mooring is attached to an offset column to provide horizontal restoring stiffness. All of the columns are connected by braces to form an integrated body. Good stability and stiffness are ensured by a large waterplane area moment of inertia to limit the platform pitch angle under wave and wind conditions. Both of the mooring lines and the floating support structure were originally developed for the DeepCwind project and also used for supporting a 5-MW HAWT in Phase II of the Offshore Code Comparison Collaboration Continuation (OC4) project. DeepCwind is a U.S. - based project aimed at generating field-test data for use in validating floating offshore wind turbine modeling tools. The OC4 project is a continuation of the OC3 project, and Phase II of the OC4 project involved modeling a semisubmersible floating offshore wind system [7]. Among various numerical codes, the FAST semi-submersible floating wind turbine numerical model was also validated by comparing with DeepCwind test data [9]. The Darrieus rotor was originally developed for the DeepWind project (2010-2014), which is a part of the FP7 European project [10]. Compared to the FHAWT of the OC4 project, the FVAWT uses the 5-MW Darrieus rotor instead of the NREL 5-MW reference turbine. The slight difference between the two floating concepts indicates that the floater must be slightly modified to adapt for the VAWT rotor, which is heavier than the HAWT rotor. The specification of the present FVAWT are detailed in [8].

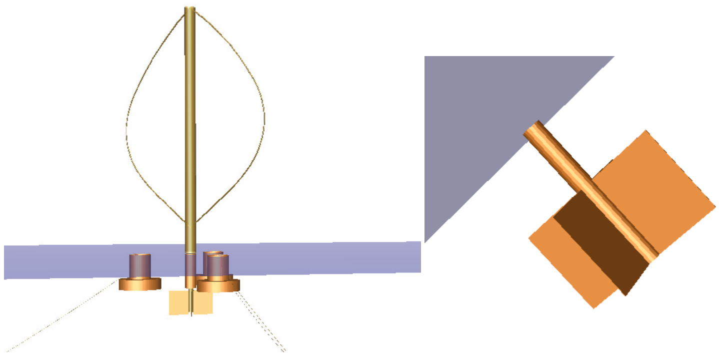

Fig. 1: (a) Floating vertical axis wind turbine; (b) Hydrodynamic brake