Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 53 (2014) 313 – 323

Energy Procedia

EERA DeepWind'2014, 11th Deep Sea Offshore Wind R&D Conference

Design of a 6-DoF Robotic Platform for Wind Tunnel Tests of Floating Wind Turbines

Bayati I.*, Belloli M., Ferrari D., Fossati F., Giberti H.

Politecnico di Milano, Dipartimento di Meccanica, Via La Masa 1, 20156, Milano, Italy

Abstract

Sophisticated computational aero-hydro-elastic tools are being developed for simulating the dynamics of Floating Offshore Wind Turbines (FOWTs). The reliabilty of such prediction tools for designers requires experimental validation. To this end, due to the lack of a large amount of full scale data available, scale tests represent a remarkable tool. Moreover, due to the combined aerodynamic and hydrodynamic contributions to the dynamics of FOWTs, experimental tests should take into account both. This paper presents the design process of a 6-Degrees-of-Freedom robot for simulating the dynamics of FOWTs in wind tunnel scale experiments, as a complementary approach with respect to ocean wind-wave basin scale tests. Extreme events were considered for the definition of the robot requirements and performance. A general overview on the possible design solutions is reported, then the machine architecture as well as the kinematic and dynamic analysis is discussed. Also a motion task related to a 5-MW Floating Offshore Wind Turbine nominal operating condition was considered and then the ability of the robot to reproduce such motions verified in terms of maximum displacements, forces and power, to be within the design boundaries.

Selection and peer-review under responsibility of SINTEF Energi AS

Keywords: Floating Offshore Wind Turbines ; Aero-hydro-elasticity; Wind Tunnel; Wind Energy; Hardware-in-the-loop; Hexapod; Hexaglide.

1. Introduction

Offshore Wind Energy is playing a significant role in facing the worldwide energy demand. In this scenario, the development of Floating Offshore Wind Turbines (FOWTs) represents a new challenge for both academia and industry, for their complexity in the design process, long-term reliability and performance assessment, investments, operations and management [1]. Nevertheless, deepwater multi-megawatt installations and strong wind resources make these challenges attractive. In the last decade, sophisticated codes have been developed to compute the coupled aerodynamics and hydrodynamics of FOWTs. Among others, the open-source aero-servo-elastic code FAST (Fatigue, Aerodynamics, Structures and Turbulence) has been developed by Jonkman J. at NREL ([2], [3]), and integrated with the hydrodynamics of the platform and mooring dynamics, by means of the module HydroDyn. More specifically, HydroDyn is able to include in FAST the frequency-dependent added mass and damping matrices and wave exciting

* Corresponding author.
E-mail: ilmasandrea.bayati@polimi.it
Tel.: +39-02-2399-8486 ; fax: +39-02-2399-8500.

Selection and peer-review under responsibility of SINTEF Energi AS
doi:10.1016/j.egypro.2014.07.240

forces, coming from the solution of the first-order potential problem (e.g from WAMIT [4]), as well as hydrostatic restoring matrix and viscous-drag forces. Therefore, the global aero-hydro dynamic model is solved by FAST, for a given sea-state (i.e Pierson-Moskovitz, Jonswap spectra), giving the possibility to simulate specific load-cases, as required by the current offshore structures standards [5].

Motivation and objectives. The sophistication of such codes, as well as the limited availability of full scale data, brings about the need of experimental campaigns for validation. First of all, the validation process requires scale test experiments, where the number of varying input parameters are reduced, controlled and correlated with the measured output. Recently scale tests of FOWTs were performed in various water basins. Remarkable results come from tests carried at Maritime Research Institute Nederlands (MARIN) where, under DeepCWind consortium [6], the global dynamic response associated to different platforms (spar, semi-summersible, tension-leg) and for different only-wave or wind-wave conditions was studied. Such tests reported the importance of developing and validating codes that combine the aerodynamics and hydrodynamics of FOWTs, tightly coupled in terms of the frequency content (i.e the second-order difference-frequency hydrodynamics and turbulence on a semisubmersible FOWT [7]). The aim of this work is to propose a complementary approach to test scale models of FOWTs [8]: more specifically, the design of a 6 degrees-of-freedom (DoF) robot, "HexaFloat", capable of reproducing the floating motion of a scale FOWT for wind tunnel experiments, is herein reported and discussed. This approach allows to investigate more thoroughly the aerodynamics of FOWTs due to different wind- and sea-states, relying on aeroelastic FOWT scale models (possibly individual pitch controlled) and the 14m×4m civil boundary layer test section of Politecnico di Milano [10], whose 35m long and constant section allows to passively or actively generate short and long turbulence length-scale (turbulence index $< 2\%$ and $> 25\%$). Therefore, the target of this work is creating a tool for better understanding the effect of hydrodynamics on the aerodynamics of FOWTs and then for validating the above mentioned aero-servo-hydro-elastic codes and giving new perspectives on the modeling of FOWTs aerodynamics, as well as pitch control strategies. Nowadays, the international effort put into the verification and experimental validation of Computer Aided Design (CAD) tools for FOWTs is remarkable. In this regards, the International Energy Agency IEA, under the coordination of National Renewable Energy Laboratory NREL, set up the Offshore Code Comparison Collaboration Continuation (OC3-OC4) [9], with the aim of sharing expertise and performing load-case benchmark excerices on FOWTs models as well as carrying out experimental validation of such codes, among various institutions, facilities and industrial partners. These collaborations have been recently extended to the OC5. From this perspective, wind tunnel tests, by means of the device presented, can play a useful role to integrate the experimental evidence emerged from scale tests carried out so far in wind-wave ocean basins. To this purpose, this work presents a customized design process of a 6-DoF robot Fig.1, for this specific application, having ability of functioning in two different configurations: providing given motion laws along single or coupled degrees of freedom or by hardware-in-the-loop mode, where motion is given in real-time consistently with the aerodynamics (measured) and hydrodynamics (computed), as extensively explained in [8].

2. Robot requirements

In order to define the requirements and the specifications for the design process of HexaFloat, in terms of maximal displacements and frequencies of the robot mobile platform, the FAST simulations by Jonkman J. [11] of three different floating platform concepts (MIT/NREL TLP, ITI Energy Barge, OC3-Hywind) were considered as reference. More specifically the worst cases of the FAST output related to the platform displacements *PtfmSurge, PtfmSway, PtfmHeave, PtfmRoll, PtfmPitch, PifmYaw* were considered. Therefore the displacement $d = (disp_{max} - disp_{min})/2$ was taken into account as extreme displacement from the nominal position and then scaled following Froude-scaling approach, with a scale length factor $\lambda_L = 1/58$, with respect to the 5MW-NREL wind turbine [12], that is compatible with the dimensions of the Politecnico di Milano wind tunnel test section [10]. Similarly, the maximum platform accelerations *PtfmTAxt, PtfmTAyt, PtfmAzt*, scaled by a factor $\lambda_a = 1$ were considered to define the maximal frequencies, assuming pure sine translations of amplitudes d. In regards to the scaling approach, the major challenge is overcoming the inability to maintain simultaneously Froude and Reynolds numbers for a scaled floating wind turbine experiments. In wind tunnel testing Reynolds number scaling is commonly used to establish model parameters in order to properly represent the relationship of viscous and inertial forces for a fluid flow, whereas in wave basin testing Froude number similitude is typically employed to properly scale the gravitational and inertial properties of wave forces, which are the