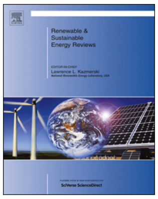
Renewable and Sustainable Energy Reviews 39 (2014) 1226–1234

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Offshore floating vertical axis wind turbines, dynamics modelling state of the art. Part II: Mooring line and structural dynamics

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ARTICLE INFO

Keywords:
Floating offshore wind turbines
VAWT
Vertical axis wind turbine
Coupled dynamics
Mooring
Structural dynamics

ABSTRACT

The need to exploit enhanced wind resources far offshore as well as in deep waters requires the use of floating support structures to become economically viable. The conventional three-bladed horizontal axis wind turbine may not continue to be the optimal design for floating applications. Therefore it is important to assess alternative concepts in this context that may be more suitable. Vertical axis wind turbines (VAWTs) are a promising concept, and it is important to first understand the coupled and relatively complex dynamics of floating VAWTs to assess their technical feasibility. As part of this task, a series of articles have been developed to present a comprehensive literature review covering the various areas of engineering expertise required to understand the coupled dynamics involved in floating VAWTs. This second article focuses on the modelling of mooring systems and structural behaviour of floating VAWTs, discussing various mathematical models and their suitability within the context of developing a model of coupled dynamics. Emphasis is placed on computational aspects of model selection and development as computational efficiency is an important aspect during preliminary design stages. This paper has been written both for researchers new to this research area, outlining underlying theory whilst providing a comprehensive review of the latest work, and for experts in this area, providing a comprehensive list of the relevant references where the details of modelling approaches may be found.

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http://dx.doi.org/10.1016/j.rser.2014.07.122
1364-0321/

1. Introduction

The need to increase renewable energy's share in global energy production and to exploit offshore wind resources is moving wind farms further offshore and into deeper waters. In depths greater than 50 m, bottom-mounted (i.e. fixed) support structures for offshore wind turbines may not remain the most economically viable option [1,2]. A transition from fixed to floating support structures is essential for deep offshore wind farms to become economically viable in the near future.

The onshore wind industry has reached a relatively mature level, with the majority of large scale wind turbines sharing the same configuration: horizontal axis of rotation, three blades, upwind, variable-speed and variable blade pitch (with feathering capability). This has been the result of several decades of research and development; originally several configurations had been considered, including horizontal axis wind turbines (HAWTs) with a different number of blades, but also vertical axis wind turbine (VAWT) configurations [3]. The conventional design emerged as the optimum techno-economic trade-off for the onshore large scale wind market.

The same “evolutionary process” did not take place for the offshore wind market, substituted by a “marinisation” of the trusted configurations used for the onshore market. It has been implicitly assumed that, despite the very different environmental conditions of an offshore environment, the optimum configuration for the wind turbine is the same i.e. the conventional three bladed, upwind, horizontal axis wind turbine. This has been implicitly assumed not only for the bottom-mounted offshore wind turbine configurations, but also for proposed floating systems. The proven technology of HAWTs aids in de-risking commercial-scale offshore wind farms.

It is therefore important to assess the technical and economic feasibilities of alternative wind turbine configurations for the offshore floating wind industry in order to ensure that the most suitable configurations are employed, with VAWTs being one promising category of wind turbines. The first step is to understand the complex dynamics of such a floating system subjected to the harsh offshore environment. As part of this task, a series of articles have been developed to present a comprehensive literature review covering the various areas of engineering expertise required to understand the coupled dynamics involved in floating VAWTs.

In part one of this series [4], an in depth review of different aerodynamic engineering models for VAWTs and their suitability for floating applications is presented. In the present second article, approaches to adequately model mooring systems and the structural behaviour of floating offshore wind turbines (FOWTs) during preliminary design stages are described and discussed, with particular emphasis on floating VAWT characteristics and computational aspects. Examples of current implementations by research groups are also reviewed. The third part in this series [5] focuses on appropriate hydrodynamic models and coupled modelling methodologies for investigating the coupled dynamics of floating VAWTs during preliminary design stages.

This paper aims to review appropriate mooring line and structural engineering models, outlining relative advantages and limitations considering floating VAWTs and impacts of model fidelity. A discussion is presented concerning the computational aspects when developing efficient coupled dynamics models and a review of current implementations used by research groups for the analysis of both floating HAWTs and VAWTs.

2. Mooring line dynamics

Mooring lines act as the station keeping system for FOWTs, maintaining the position of the FOWT on the sea surface as well as contributing to platform stability under environmental loading. Whilst the importance of mooring line modelling may be sometimes overlooked in FOWT coupled dynamics modelling, mooring lines are critical to platform dynamic response. In the wider offshore industry two different types of mooring lines have been used predominantly [6]:

1. Catenary mooring lines: are freely hanging chain lines or wires connecting a floating surface platform to anchors on the seabed some distance from the platform. A combination of the mooring line mass and anchor horizontal forces maintain station-keeping of the platform (restricting the surge, sway, and yaw degrees of freedom). An example is depicted in Fig. 1a.
2. Tensioned mooring lines: Taut, lightweight elastic lines that are connected vertically (Fig. 1c) or at an incline (Fig. 1b, also known as spread moorings) to the platform maintain platform position through elastic forces when the platform perturbs from its equilibrium position. Differently from the previous, it generates significant restoring forces in all the six DOF.

In very deep waters, mooring systems can represent a significant cost of the total system, and whilst this is not such a significant issue with the offshore oil and gas industry where

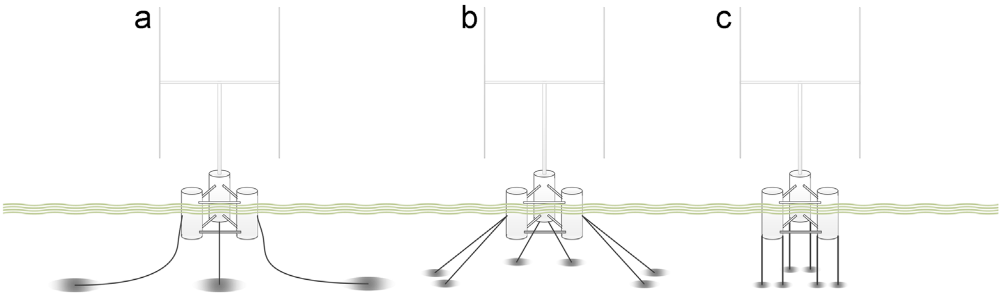

Fig. 1. Simplified typical floating semi-submersible VAWT schematic highlighting: (a) catenary mooring lines; (b) inclined tensioned/spread moorings; (c) vertical tensioned moorings.