Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 80 (2015) 255 – 262

Energy Procedia

12th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2015

Coupled mooring systems for floating wind farms

Marek Goldschmidt*, Michael Muskulus

Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Høgskoleringen 7A, 7491 Trondheim, Norway

Abstract

In this paper it is investigated if, by coupling the catenary mooring systems of a number of turbines, the number of lines and anchors needed and subsequently the costs could be reduced and what kind of dynamic phenomena such a mooring system will exhibit. A row, triangular and rectangular arrangement of floating wind turbines is analyzed in terms of their cost saving potential and their dynamic properties in the frequency domain. The row arrangement is further investigated in the time domain, with a one dimensional simplified model. The most important forces to evaluate the station keeping performance, except current, are applied. These consist of irregular wave forces, employing the Morison equation, estimated wave drift and wind forces. Diffraction effects have been estimated by employing the McCamy-Fuchs theory. Four operational and a 50-year extreme load case have been applied. The results are showing that significant cost reductions of up to 60% in mooring system and 8% in total system costs could be achieved. The dynamic analysis shows the general feasibility of integrated mooring systems. No resonance problems seem to exist. However displacements are increasing with the number of floaters, and cost savings diminish for larger numbers of turbines, as the required diameters, lengths and costs of mooring chains increase.

Peer-review under responsibility of SINTEF Energi AS

Keywords: Coupled mooring system, Frequency domain, Time domain, Catenary, Floating wind turbines, Semi-submersible

1. Introduction

At sites with very high water depths traditional support structures for offshore wind turbines such as monopiles, jackets, tripods, or tripiles suffer from unfavorable economic performance. The concept of floating offshore wind turbines (FOWT) seems to be an appropriate solution. However, the mooring system incurs a significant cost. It is

* Corresponding author. Tel.: +49-1577-1954170.
E-mail addresses: goldschmidtmarek@gmail.com (Marek Goldschmidt), michael.muskulus@ntnu.no (Michael Muskulus)

Peer-review under responsibility of SINTEF Energi AS
doi:10.1016/j.egypro.2015.11.429

therefore interesting to study if, by coupling the individual catenary mooring systems of a number of turbines, the number of lines and anchors needed and subsequently the cost could be reduced. The aim is to understand the potential cost reductions and what kind of dynamic phenomena such a mooring system will exhibit. In this work a semi-submersible floater equipped with a wind turbine will be used as example. The dynamics of semi-submersibles and catenary mooring systems are well known from the oil & gas industry and described by e.g. Barltrop [1], Chakrabarti [2] and Faltinsen [4]. An integrated mooring system has been investigated by Gao & Moan in [7], where multiple floating wave energy converters were moored using taut lines with buoys. Oceanwind Technology LLC has described coupled mooring systems for floating offshore wind farms in their patent [11]. Fredriksson et al. used an integrated mooring system in [6], where numerical modeling techniques for large fish farms are studied and compared to mooring tension measurements.

Mooring systems provide station keeping for floating offshore wind turbines, by keeping the translational motions in surge & sway and the rotational motions in yaw within the specified limits. To evaluate the feasibility of a mooring system design, the station keeping performance is therefore an important criterion. In this work only translational motions in surge and sway are considered, yaw motions are neglected.

Different wind farm layouts (row, rectangular and triangular arrangements, see Fig. 1 a-c, respectively), are analyzed in terms of their dynamic properties in the frequency domain and their cost saving potential. The row arrangement, simplified as a one dimensional system, has been further investigated in the time domain. Two coupled row-configurations with 5 and 10 FOWTs in a row are studied and compared to each other and a traditional moored turbine, with 2 anchor lines.

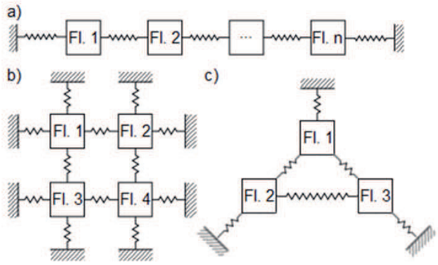

Fig. 1. Wind farm layouts: a) row, b) rectangular, c) triangular

2. Implementation

2.1. Floater and mooring systems

In this work the "DeepC" semi-submersible floating offshore wind turbine from phase II of the OC4 project is used as an example [8]. A NREL 5 MW baseline wind turbine is based on a main column, which is centered between three offset columns. The dimensions and properties of the structure are shown in Table 1 and Fig. 2. For simplification the braces are ignored and the diameter of the offset columns is assumed to be solely 12m, including the base columns. Even so the floater is designed to have a mooring system setup of three lines, one line connected to each of the three offset columns; it is also used with two and four mooring lines in this work. It is an adequate approach to compare different mooring system layouts, as only the total system dynamic is to be studied and yaw rotations are ignored. The mooring system properties of three investigated layouts are shown in Table 2; note that some properties are only valid for configurations with 2 row, 3 triangular and 4 rectangular arranged FOWTs. An anchored line is connected with one end to a floater and the other end to an anchor at the seabed. Two neighboring floaters are connected via a somewhat shorter line that is freely hanging (termed coupled line in Table 2).

Table 1. Floater properties

FOWT system mass [kilotons]	13.47
Draft [m]	20
Depth to fairleads below SWL [m]	14
Elevation of offset columns above SWL [m]	12
Diameter of main column [m]	6.5
Diameter of upper offset columns [m]	12

Table 2. Mooring system properties

Floater arrangement	row	triangular	rectangular
Water depth [m]	200	200	200
Number of lines connected to FOWT	2	3[1]	4
Angle between adjacent lines [deg]	180	various	90
Anchored/coupled line length [m]	835.7[1]/677.9[1]	838.1[1]/677.9[1]	835.7[1]/677.9[1]
Anch./coupl. horizontal distance [m]	792.9[1]/640.0[1]	794.3[1]/640.0[1]	792.9[1]/640.0[1]
Diameter of mooring chain [mm]	92[1]	100.2[1]	92[1]
Mass of chain [kg/m]	156.9[1]	185.0[1]	156.9[1]

[1]only valid for the smallest possible coupled setups (2 in a row, 3 triangular & 4 rectangular)