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Wake losses optimization of offshore wind farms with moveable floating wind turbines

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ABSTRACT

In the future, floating wind turbines could be used to harvest energy in deep offshore areas where higher wind mean speeds are observed. Currently, several floating turbine concepts are being designed and tested in small scale projects; in particular, one concept allows the turbine to move after installation. This article presents a novel layout optimization framework for wind farms composed of moveable floating turbines. The proposed framework uses an evolutionary optimization strategy in a nested configuration which simultaneously optimizes the anchoring locations and the wind turbine position within the mooring lines for each individual wind direction. The results show that maximum energy production is obtained when moveable wind turbines are deployed in an optimized layout. In conclusion, the framework represents a new design optimization tool for future offshore wind farms composed of moveable floating turbines.

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1. Introduction

The need for steadier and higher mean wind speeds has been pushing the offshore wind industry towards areas located further from the coast [1]. In fact, both the average distance to shore and water depth of offshore wind projects has been increasing since the industry first steps (Fig. 1). However, current turbine grounded support structures are only economical viable to certain water depths ranges [2].

With the desire of moving to locations with deeper water depths, in an economically viable way, floating wind turbines concepts have appeared in the last years. Currently, there are several floating turbine concepts being developed and tested in pilot projects [3,2]. One of these floating turbine concepts is developed by the IDEOL company [4]. This specific design takes another advantage from the fact that a flowing turbine is not bottom-fixed to the seabed: it allows the turbine to have a certain mobility freedom even after its installation [4].

To reduce costs, e.g. cabling and area rental costs, turbines tend to be packed in wind farms. However, installing turbines close to each other causes interferences such as wake losses through shadowing. For example, the efficiency of the Danish Horns Rev I offshore wind farm is 89% of what the same turbines would produce if installed alone [5]. Thus, it is important to reduce the wake losses in far and large offshore wind farms. One possible strategy to reduce wake losses is to optimize the wind farm layout.

The wind farm layout optimization problem has been intensively studied in the last years [6–15]. More specifically, the first work that dealt with the wind farm layout problem was carried out back in 1994 [16]. The wind farm area was grid-discretized and the optimizer was set to obtain layouts that would increase the wind farm efficiency. The first work that considered the wind farm space as a continuous space was carried out in [17], whereas the first optimization approach tailored for offshore environments was presented in [18].

Although a great deal of research has been conducted in the wind farm layout optimization problem, all investigations solely considered the possibility of optimizing the turbine locations before construction. Hence, so far no strategy has been developed which considers the possibility of moving the wind turbines after the project commissioning. This work presents a novel optimization framework for offshore wind projects composed of moveable wind turbines.

The work is organized as follows: the next section introduces the different types of floating wind turbines that currently exist, followed by a detailed explanation of the moveable wind turbine concept. Thereafter, in Section 3, the novel optimization framework is proposed. Section 4 presents the wake loss models used

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in this work, whereas Section 5 presents a case study specifically designed to evaluate the proposed approach. In Section 6 the results are presented and an analysis is carried out. The article closes with general conclusions and recommendations for offshore wind and future research.

2. Floating wind turbines

Existing commercial-size offshore wind farms make use of grounded substructure concepts to support their turbines. Such substructures become very expensive and difficult to engineer as the water depth increases. Hitherto, water depths higher than 50 m require floating support structures. In fact, as shown in Fig. 2, only a demonstration offshore project, Beatrice Demonstration, uses grounded support structures at a location with an average water depth higher than 40 m [3].

Many countries have a limited number of suitable sites in sufficiently shallow water to allow economically viable fixed substructures. Within Europe, much of the Mediterranean and Atlantic basins as well as Norway face this difficulty [19]. In the long term, it is anticipated that floating structures will become prominent in the offshore wind market [19]. There are several advantages for using floating turbines:

- Access to previously inaccessible places where there is stronger yet less turbulent winds [20].
- More flexible construction and installation phases [19].
- Possible commissioning and assembly at the quayside, avoiding the need for heavy-lift jack-up or dynamic positioning vessels, further reducing the cost and risk of deployment activities [20].
- Avoiding piling activities during installation and an easier decommissioning processes lead to reduced environmental impacts and sea life disturbance.
- Geotechnical requirements are reduced since core sampling is only needed at the anchor positions, as opposed to the necessity of deep core sampling at every pile site [20].

Nonetheless, there are several challenges related to floating wind turbines. For example, the increased wind and wave-induced motion, the added complexity of the design process, electrical infrastructure design and costs (in particular the flexible cable), construction, installation and O&M procedures [19]. However,

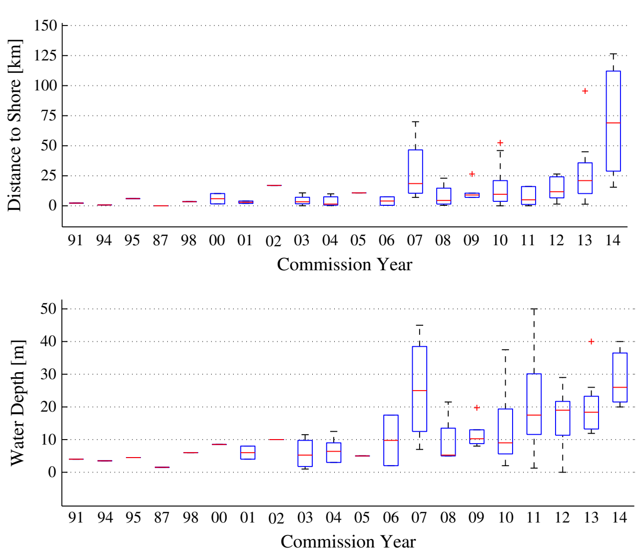

Fig. 1. Average distance to shore and water depth for commissioned offshore wind projects: aggregated values for all the projects commissioned in the same year [23,58].

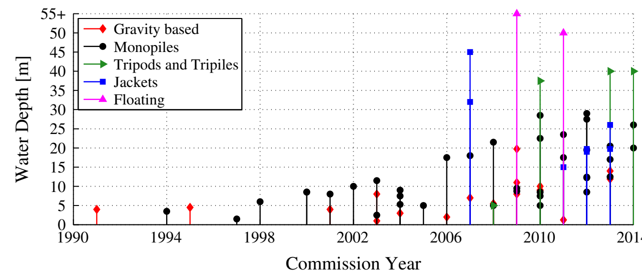

Fig. 2. Average water depth per offshore project [23,58].

increased know-how and standardization practices will contribute to overcoming these challenges. Furthermore, it is also expected that a higher energy production will be achieved since the floating turbines will be deployed at sites with higher mean wind speeds. Currently the existing floating concepts may be categorized in three main types [21]:

- Buoyancy: employs a barge type device with catenary mooring lines.
- Mooring Line: under water chains or tethers connect the buoyant body to a counterweight that lies on the seabed [2]. With the buoyant body semi-submerged in the water, the necessary uplifting force is created, keeping the chains constantly tensioned [22].
- Ballast: uses spar buoy platforms with catenary mooring anchors.

2.1. Moveable wind turbine concept

IDEOL developed a new floating turbine concept, which allows the structure to move along its mooring lines [4]. Fig. 3a shows the basic version of a moveable turbine, which only allows for linear movements (one degree of freedom). This system is easier to operate since the turbine position is set by only one parameter, e.g. the distance from one the anchoring positions. Fig. 3b illustrates a more complex design which, by rearranging the anchoring positions, allows the turbine to cover a triangular area. This new anchoring configuration gives two degrees of freedom to the turbines, thus it allows them to move in two directions. Although, this system results in a higher maneuverability of the turbine, it increases the control complexity since two coordinates have to be set to position the turbine.

With this mobility, it becomes possible to optimize the wind farm layout based on different environmental data, e.g. wind and tidal direction. Hence, this solution allows for wake losses reduction, leading to an increased annual energy production. On the other hand, this concept is more complex than a similar floating concept due to the extra mobility machinery and attached complexity. Furthermore, they are logistically more complex, since it requires a system operator to move the turbines according to the wind direction. Nonetheless, reducing wake losses through a real time wind farm layout optimization according to the wind direction may bring energy gains which might overcome the shortcomings.

The wind direction is a key factor for the turbine mobility approach. Since the turbine mobility is somehow limited, the layout adjustment may be limited to more persistent wind direction alterations while disregarding fast wind direction transients. Therefore, the decision of moving the turbines should be based on data from meteorological masts and weather forecast to guarantee that there is an energy generation benefit to the repositioning.

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