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Optimizing Jack-up vessel strategies for maintaining offshore wind farms

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Abstract

In this paper we present a new two-stage stochastic mathematical programming model that determines the optimal jack-up vessel strategy for an offshore wind farm. Given an offshore wind farm site, and distance to shore the model decides when, and for how long, a jack-up vessel should be chartered in order to minimize the total expected cost. The model considers both chartering and operational costs of the jack-up vessels, and the downtime costs of the wind farm which occurs when the wind turbines are not producing electricity. The model considers uncertainty both in the weather conditions and in when and how many components fail each year at the wind farm.

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1. Introduction

Between 2000 and 2012, the world's electricity consumption increased by about 48% [1], and it is projected that the consumption will continue to grow in the future. Currently, fossil fuels constitute about 67% of electricity generated worldwide [2], with approximately the same numbers emerging in Europe [3]. The EU goals for 2020 state that 20% of the energy consumption in EU countries should come from renewables [4], and this will further increase the focus on green energy in the coming years. One of the most popular sources of renewable energy to be exploited in recent decades is wind energy. Traditionally, wind energy has been produced by wind turbines placed on land, but in the past decade there has been an increase in electricity delivered to the European market by offshore wind farms. In 2015, 419 new offshore wind turbines were installed in Europe and six new projects were under construction. Total grid-connected capacity at year end was about 11.0 GW. When completed, the six projects expand the capacity further by 1.9 GW [5].

There are several reasons for wind turbines to be installed offshore rather than onshore, the most important being space. Offshore installation allows for wind farms with both more and larger turbines being located where wind conditions are more stable and favorable, thus increasing production. Furthermore, noise and visual effects are minimized.

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However, currently, offshore wind is not financially competitive with lifetime levelized costs being 59% higher than onshore wind and about 127% higher than fossil fuels [6]. The elevated costs of offshore wind energy are caused by significant installation as well as operations and maintenance (O&M), costs. Currently, O&M costs constitute about one-third of lifetime costs [7]. This includes spare parts, transportation, technician salaries and costs of repair actions as well as lost revenue due to turbines not producing electricity (hence forward referred to as *downtime cost*). In addition, the harsher weather conditions offshore increase the failure rate, and decrease accessibility, with the availability of the turbines being significantly lower than for those located onshore [8]. Thus, the opportunities for conducting maintenance are limited and expensive as extended periods of favorable weather are required. This is especially true in winter, when weather conditions become worse and downtime for turbines can be extensive.

One way to make offshore wind more financially competitive, is to reduce O&M costs. Vessel chartering constitutes around 70% of lifetime O&M costs [9], and decision supporting tools for this problem are limited. The single most expensive O&M cost is that of chartering jack-up vessels, which can have charter rates as high as GBP 287 000 per day [9]. Jack-up vessels use a number of extendable legs that elevates the hull above the sea surface for stabilization purposes and are equipped with a crane capable of lifting heavy components. In an O&M setting they are used when replacing major components on a wind turbine such as blades, gearboxes, transformers, and generators, which are too heavy for regular maintenance vessels.

Breakdown and replacement of such heavy components are rare events, and are difficult to predict. Therefore one ideally would like to charter a jack-up vessel after a breakdown has occurred. However, this is a difficult strategy for several reasons. First, there is a limited market for jack-up vessels, and there is often a mobilization time of several months between a vessel is chartered and it is available to the charterer. Second, chartering a jack-up vessel is expensive, and the charter rate is higher the shorter the mobilization time. Third, due to the high costs of chartering jack-up vessels it is (in most cases) not profitable to charter a jack-up vessel to replace a single component, but rather to wait until a given number of replacements are needed. However, due to the mobilization time there is still significant uncertainty in the number of additional breakdowns that require replacement between the time the jack-up vessel is chartered and the time it is available. Finally, since both the jacking operations and lifting operations performed during a replacement is restricted by the weather conditions, it is not possible to know at the time of chartering the jack-up vessel, how long the replacements will take.

Jack-up vessel chartering strategies for offshore wind farms have previously been studied by [9], where a simulation model is used to compare a set of different strategies. However, they only conduct a sensitivity study by simulating a small subset of the possible chartering strategies. In addition, they do not decide when the Jack-up vessel is chartered, and do not consider the option of chartering a vessel in several shorter intervals each year. Related fleet size and mix problems for offshore wind farms that focus primarily on crew transfer vessels have previously been studied by [10] and [11]. In [10] a deterministic optimization model of the problem is presented, while [11] studies a three-stage stochastic optimization model to determine the optimal fleet of vessels to perform maintenance at offshore wind farms. Both these papers consider a planning horizon of one year that represents a typical year of maintenance of the offshore wind farm. [12] include long-term uncertainty in the development of the wind farm over time. The decisions include not only which vessels to invest in, but also how long to charter each vessel for, with an opportunity to replace vessels later on, as the wind farm evolves. However, even though [10–12] all include the opportunity to add jack-up vessels, neither of them focus on modelling jack-up operations in detail, something which is done in this work.

In this paper we present a two-stage stochastic programming model that finds the optimal jack-up chartering strategy for a given offshore wind farm. The aim is to decide when, and for how long, to charter jack-up vessels, based on probabilistic information regarding the weather conditions at the offshore wind farm and the failure rates of components requiring jack-up vessels to replace. The advantage of using this type of model is that the wind farm operator can decide well in advance, when to charter a jack-up vessel, thus get lower mobilization costs, and enable better planning of its O&M activities.

In Section 2 we give a formal description of the optimal jack-up chartering strategy problem, together with a stochastic programming model of the problem. In Section 3 we discuss how the model may be solved, before finally, giving some concluding remarks in Section 4.