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A metaheuristic solution method for optimizing vessel fleet size and mix for maintenance operations at offshore wind farms under uncertainty

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Abstract

Maintenance operations at offshore wind farms are challenging due to the offshore element; maintenance technicians and spare parts need to be transported from an onshore port or offshore station to the individual wind farm components in need of maintenance. The vessel resources needed to support these maintenance tasks constitute a major part of the total maintenance costs, and hence up-keeping an optimal vessel fleet and corresponding deployment is essential to reduce cost-of-energy. This paper introduces a metaheuristic solution method to determine cost-efficient vessel fleets to support maintenance tasks at offshore wind farms under uncertainty. It considers weather conditions and failures leading to corrective maintenance tasks as stochastic parameters, and evaluates candidate solutions by a simulation program. The solution method has been incorporated in a decision support tool. Computational experiments, including comparison of results with an exact solution method, illustrate that the decision support tool can be used to provide near-optimal solutions within acceptable computational time.

Keywords: offshore wind; operation and maintenance; operations research; fleet composition; decision support; metaheuristic

1. Introduction

The costs of vessels, helicopters and related infrastructure to support operation and maintenance (O&M) tasks are amongst the largest contributors to the total costs of the operational phase of an offshore wind farm. For a typical offshore wind turbine with a life span of twenty years, the total O&M costs account for around 20 % to 35 % of the total life cycle costs [1].

Maintenance logistics is an important competitive factor in the offshore wind energy industry having a significant impact on the profitability of offshore wind projects [2]. For the time being the offshore wind energy industry is dependent on financial support to be profitable. One means to reduce the costs of maintenance logistics is to select

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cost-efficient vessel fleets to support the O&M tasks. In this paper, vessel is used as a general term and include both potential vessel and helicopter resources.

In the existing literature, there are only a few studies on the use of optimization models to determine optimal vessel fleets for maintenance operations at offshore wind farms. A deterministic model was proposed in [3], that was extended to a stochastic model in [4]. Stochastic optimization models have also been proposed in [5] and [6].

Most of the related existing literature and decision support tools to evaluate maintenance logistics are based on simulation models. A review of decision support systems for offshore wind farms with an emphasis on O&M strategies is provided in [7], and a comparison of some simulation models and the optimization model proposed in [6] is presented in [8].

This paper presents a new metaheuristic solution method for the offshore wind O&M vessel fleet optimization problem. The method consists of two steps: First a quick construction heuristic is used to generate a feasible starting solution. Then a local search improvement algorithm will evaluate the neighborhood solutions of the starting solution. The method considers weather conditions and failures resulting in corrective maintenance tasks as stochastic parameters and evaluates each candidate solutions by a simulation program. It has been incorporated into a decision support tool (DST) that can be used by actors in the offshore wind industry to find and evaluate optimal vessel resources for the O&M phase for offshore wind farms.

The rest of the paper is organized as follows: Section 2 provides a problem description and a verbal description of the mathematical problem formulation that the metaheuristic solution method is based upon. Then Section 3 presents the metaheuristic solution methodology and gives a brief description of the decision support tool in which it has been incorporated. In Section 4 a computational study is presented before the paper is concluded in Section 5.

2. Problem description and formulation

An offshore wind farm is described by its distance to onshore ports, its internal travel distances (used to calculate average travel distance between turbines for execution of maintenance operations), number of turbines, installed capacity per turbine and the turbines' power curve. The problem considered is to determine vessel fleet size and mix to support the maintenance operations at a wind farm. A planning horizon of one year is considered, and the vessel resources may be long-term chartered, i.e. for the whole year, or short-term chartered where a charter term is defined to be one calendar month.

Maintenance operations at a wind farm can be split in two main categories: Preventive and corrective maintenance tasks. Preventive tasks are carried out at predetermined intervals or according to prescribed criteria from turbine manufacturers, and intend to reduce the probability of failure or the degradation of the function of an item. These types of maintenance tasks are typically given a long time window for execution, e.g. 3-6 months (maintenance campaign). It is assumed that the turbines need to be shut down for maintenance during execution of preventive maintenance tasks, and hence a downtime cost is induced equal to the lost income due to lost energy production. Corrective tasks need to be executed whenever there is a component failure resulting in a need for repair or replacement. The need for execution of corrective maintenance tasks will not be known until a failure occurs, and it is assumed that such component failures result in system malfunction, e.g. a component failure at a turbine will result in a turbine shutdown. Hence, a downtime cost is induced for these maintenance tasks equal to the lost income due to lost energy production from the time of the failure until the corrective task has been executed.

Maintenance tasks will require up to three different types of activities requiring vessel resources: Transportation of maintenance technicians, transportation of spare-parts and equipment, and lifting activities. For tasks requiring only maintenance technicians, i.e. a vessel resource does not need to be present at the turbine to execute the task, a vessel resource can support several tasks in parallel by dropping-off teams of maintenance technicians at the turbines and return to pick-up the teams upon finalization of the work or at the end of the work shift. Discussions with industry regarding safety regulations suggests that the limit of such parallel tasks should be four. A penalty cost applies for all maintenance tasks not executed within the planning horizon. To account for end-effects, maintenance tasks that are to be executed shortly before the end of the planning horizon (year) may be executed at the start of the planning horizon.

Potential vessel fleets used to support O&M tasks at offshore wind farms consist of a mix of vessels and helicopters with different operational criteria. All vessel resources need to be associated with a maintenance base that can be e.g. an onshore port or an offshore station. Onshore ports and offshore stations have a given distance to the offshore wind