Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 94 (2016) 357 – 366

Energy Procedia

13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016

Vessel fleet optimization for maintenance operations at offshore wind farms under uncertainty

Magnus Stålhane[a,*], Hanne Vefsnmo[a], Elin E. Halvorsen-Weare[b], Lars Magnus Hvattum[c], Lars Magne Nonås[b]

[a]*Department of Industrial Economics and Technology Management, NTNU, Alfred Getz veg 3, NO-7491 Trondheim, Norway*
[b]*Department of Maritime Transport Systems, MARINTEK, POB 4125 Valentinlyst, NO-7450 Trondheim, Norway*
[c]*Faculty of Logistics, Molde University College, Britveien 2, NO-6410 Molde, Norway*

Abstract

In this paper we consider the problem of determining the optimal fleet size and mix of vessels to support maintenance activities at offshore wind farms. A two-stage stochastic programming model is proposed where uncertainty in demand and weather conditions are taken into account. The model aims to consider the whole life span of an offshore wind farm, and should at the same time remain solvable for realistically sized problem instances. The results from a computational study based on realistic data is provided.

Peer-review under responsibility of SINTEF Energi AS
Keywords: Fleet-size-and-mix; Operations & maintenance; Stochastic programming.

1. Introduction

Today, the offshore wind energy industry needs financial support to be profitable, and producers in the United Kingdom receive a subsidy of approximately EUR 100 per produced MWh [1]. Following the initial investment, the largest cost component is the cost of operations and maintenance (O&M) activities, which may constitute between 20–25 % of the life-cycle costs of an offshore wind turbine [2]. The yearly cost of O&M activities at offshore wind farms could be anywhere between GBP 50 000 and GBP 100 000 per turbine [3]. The sum depends on a range of factors including location, machine size, and how well the O&M activities are organized. A significant reduction in these costs is needed to make offshore wind farms a competitive alternative to other energy sources. Therefore it is of importance to select a cost-effective fleet size and mix of vessels to support the O&M activities.

This paper presents a new mathematical programming model that determines the optimal fleet of maintenance vessels to support the O&M activities at one or more offshore wind farms. The problem modeled is faced by offshore wind farm operators which operate one or more wind farms that are expanded over time. As the wind farms grow both

* Corresponding author. Tel.: +47 73593084.
E-mail address: magnus.stalhane@iot.ntnu.no

Peer-review under responsibility of SINTEF Energi AS
doi:10.1016/j.egypro.2016.09.195

in covered area and in number of turbines, the fleet of maintenance vessels must be adapted to handle an increased demand for O&M activities, greater distances, and more volatile weather conditions.

The remainder of this paper is structured as follows. Section 2 provides a description of the problem. A mathematical formulation of the problem is given in Section 3. A computational study follows in Section 4, and concluding remarks are found in Section 5.

2. Problem description

The cost of vessels, helicopters and infrastructure used to support O&M activities is one of the largest cost elements during the operational phase of an offshore wind farm. The vessel fleet size and mix is determined from a heterogeneous set of vessels and helicopters that can be purchased, or chartered for shorter periods of time. Purchased vessels may be chartered out in time periods where they are not used. Large wind farms will be developed in several building steps, and the requirements of the vessel fleet to support O&M activities will increase as more turbines become available in each new building step. Hence, the optimal vessel fleet may change over time.

The vessels in the fleet can operate from onshore or offshore bases. An onshore base can be any given port, and offshore bases can be, for example, artificial islands or mother vessels. The number of vessels that can operate from a base is limited. Offshore bases can be advantageous for wind farms far offshore where the travel time to onshore ports make it hard for vessels to do a return trip from shore to the wind farm during a normal work shift. The offshore bases will have large investment costs and are unlikely to be profitable for single, small wind farms. Knowledge about development of future wind farms, with which an offshore base can be shared, can make it profitable to invest in one at an early stage. Thus, the planning horizon needs to cover the entire life span of an offshore wind farm to properly evaluate such opportunities.

All vessels cannot be used to support all types of O&M activities. Supply vessels can be used to transport maintenance personnel and small equipment. If large components need to be changed, a crane vessel or jack-up vessel is required. Helicopters and smaller vessels can only transport maintenance personnel, but can do so at a higher speed.

The distance between a vessel's base and the wind farm affects the transfer time, which again affects the time a vessel can be used to support O&M activities at the wind farm before returning to its base. Vessels with high transfer speed are valuable if this distance is great. Also, increased distance between an offshore wind farm and the shore will make an investment in an offshore base more profitable.

A long term plan for purchasing vessels is important as there is usually a time delay between entering a contract to purchase a vessel and its delivery. Some vessel types will be available for charter at a daily rate. The demand for vessels may, however, exceed the supply for such vessels, especially during times of the year when weather conditions are expected to be good. For this reason, an offshore wind operator will seek to enter into charter contracts well ahead of the start of the charter period. Hence, the timing for purchasing or chartering vessels is of importance.

There are two main types of O&M activities that must be supported by the vessel fleet: preventive and corrective. The preventive type consists of planned activities that intend to guard against component failures. Typical examples are visual inspection, changing of consumables, oil sampling, and tightening of bolts [4]. These activities can be postponed, but should be performed regularly to reduce the risk of future failures. The cost of preventive maintenance activities is the sum of transportation cost, personnel cost, equipment cost and the cost of lost production due to turbine shut-down when the activity is being performed. Corrective maintenance activities occur when there is a component failure followed by a production stop. There will be an immediate loss of income due to the production stop, and this loss will continue to grow until the corrective maintenance activity has been performed and production can restart. The total cost of corrective maintenance activities is the sum of transportation cost, personnel cost, equipment cost and the loss in revenue due to the production stop.

There are many uncertain parameters affecting the execution of O&M activities at offshore wind farms. Today, the industry is immature and expensive, and any new wind farm developments depend on government subsidies to make it a viable investment. The industry actors are concerned with the accessibility (access to) and availability (produced electricity vs. theoretical potential for electricity production) of a wind farm. The former is highly related to weather conditions, and the vessels and access system used, while the latter is related to both the time it takes to repair a failure and the number of failures. Hence, the focus in this paper is on uncertainty in weather conditions, and the occurrence of turbine failures that result in corrective maintenance activities. There are several weather parameters