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Optimisation of maintenance routing and scheduling for offshore wind farms

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A B S T R A C T

An optimisation model and a solution method for maintenance routing and scheduling at offshore wind farms are proposed. The model finds the optimal schedule for maintaining the turbines and the optimal routes for the crew transfer vessels to service the turbines along with the number of technicians required for each vessel. The model takes into account multiple vessels, multiple periods (days), multiple Operation & Maintenance (O&M) bases, and multiple wind farms. We develop an algorithm based on the Dantzig–Wolfe decomposition method, where a mixed integer linear program is solved for each subset of turbines to generate all feasible routes and maintenance schedules for the vessels for each period. The routes have to consider several constraints such as weather conditions, the availability of vessels, and the number of technicians available at the O&M base. An integer linear program model is then proposed to find the optimal route configuration along with the maintenance schedules that minimise maintenance costs, including travel, technician and penalty costs. The computational experiments show that the proposed optimisation model and solution method find optimal solutions to the problem in reasonable computing times.

1. Introduction

The development of offshore wind farms has been significant over the past 20 years. One of the reasons for this growth is that a wind turbine at sea generally produces more electricity than that of its onshore equivalent as the average wind speed at sea is higher. However, the installation, operation, and maintenance costs are also much higher for offshore wind turbines, since more resources and infrastructures are needed to install and maintain a wind turbine at sea. According to Snyder and Kaiser (2009), the operations and maintenance costs could contribute a quarter of the life-cycle costs, making it one of the largest cost components of an offshore wind farm. One way to reduce the costs is to make the maintenance activities more efficient by optimising maintenance schedules and the routing of maintenance vessels. This potential for cost reduction becomes increasingly important as wind farms become larger and constructed farther from shore, increasing the vessel travel times both to and within the wind farms.

According to European Committee for Standardization (2010), maintenance activities in wind power systems involve corrective maintenance, predetermined (preventive) maintenance, and condition-based maintenance. Corrective maintenance is performed following detection of a failure where the aim of this maintenance is to restore normal operating conditions. Predetermined preventive maintenance is conducted at predetermined intervals or based on prescribed criteria such as the age of the equipment and production schedule. This maintenance aims to reduce the failure risk or performance degradation of the equipment. Condition-based maintenance is done by assessing the actual equipment condition using inspection or (on-line) condition monitoring. The maintenance activity is performed when there are indicators which give information that the system is deteriorating and the probability of failure is rising. In this paper, we deal with the maintenance scheduling problem where the recommended period for a set of turbines that need to be maintained is given. The turbines can be selected based on the principles of predetermined preventive maintenance or condition-based maintenance. A penalty cost is

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incurred in the model when the maintenance activity is performed after the recommended period.

Maintenance scheduling for offshore wind farms is a complex and challenging problem (Shafiee, 2015). The main goal of maintenance scheduling is to construct a detailed schedule of maintenance activities that have to be performed within a planning horizon. There are several factors that need to be considered when scheduling the maintenance activities of an offshore wind farm including the weather conditions, the availability of various resources (e.g. service vessels, crews, and spare parts), and the disruption to electricity generation. Resources needed for maintaining the offshore turbines are commonly based at the nearest port or Operation & Maintenance (O&M) base. The weather conditions (such as wind speed and wave height) and the vessel availability are the main factors that affect the performance of the maintenance activities. For safety reasons, the maintenance can only be performed in periods where the required weather conditions are met. As good weather periods are limited in most locations where wind farms are currently located or being planned, maintenance schedules must be optimised to exploit the resulting weather windows. Once the maintenance schedules have been fixed (the period when the turbines in the wind farms will be serviced/visited), other aspects required to be addressed are as follows: the type of vessels that will be used for each period; the optimal route for each selected vessel to visit the set of turbines in the wind farms; and the number of each skill type of technicians required by each vessel for the given maintenance schedule and vessel route. Therefore, the maintenance problem of an offshore wind farm is a complex problem and difficult to solve to optimality.

The main contributions of this paper include: (i) Presenting a new routing and scheduling problem from the offshore wind industry that considers several logistics bases and the possibility of servicing more than one wind farms with the same fleet. (ii) Proposing a new mathematical model and solution method to solve the problem. (iii) Obtaining new optimal solutions for a set of benchmark problems from the literature along with the solutions for new more challenging problems.

The paper is organised as follows: Section 2 presents a description of the maintenance routing and scheduling problem for offshore wind farms, a brief review on maintenance scheduling in offshore wind farms, and an overview of related routing problems. Section 3 gives a description of the maintenance routing and scheduling problem for offshore wind farm. Section 4 presents the optimisation model and solution method for solving the maintenance routing and scheduling problem. Section 5 presents the computational results on the data available in the literature and new randomly generated data. The last section provides a summary of our findings and some avenues for future research.

2. Literature review

2.1. Maintenance routing and scheduling for offshore wind farms

The maintenance routing and scheduling problem for an offshore wind farm was introduced by Dai, Stålhane, and Utne (2015). The problem consists of finding one route and schedule for each vessel to perform maintenance on a set of wind turbines over a planning period of several days. The model takes into account a penalty cost if the turbines are maintained after the recommended period. The model also considers the capacity of vessels in transporting technicians and spare parts. Stålhane, Hvattum, and Skaar (2015) study the problem proposed by Dai et al. (2015), but consider only one period. They propose an arc-flow model of the problem, and reformulate it as a path-flow model by using Dantzig–Wolfe decomposition (Dantzig and Wolfe, 1960). The re-formulated problem is solved as a mixed integer program, where a subset of possible routes and schedules are generated heuristically.

The papers mentioned above only consider one O&M base and one wind farm. However, some wind farm operators or O&M service providers may serve multiple offshore wind farms in the same area, and may use multiple ports as the base for conducting O&M. This may be increasingly relevant to consider as more clusters of neighbouring wind farms are being developed, allowing more resources to being shared between them. To the best of our knowledge, there is no paper in the literature dealing with maintenance routing and scheduling problem for multiple wind farms and O&M bases. Therefore, in this paper, we propose a new mathematical model and a solution method to tackle such a problem. In addition, we take into account the number of each skill type of technicians available at each O&M base, the availability of the vessels and spare parts, and the ability of a vessel to transfer spare parts.

2.2. Review on maintenance scheduling problems for offshore wind farms

This subsection presents an overview of related maintenance scheduling problems from the wind energy sector. We begin by giving an overview of predetermined preventive maintenance scheduling, and then presenting papers studying corrective and condition-based maintenance scheduling.

2.2.1. Predetermined preventive maintenance

A mathematical model for determining the best time for maintenance operations taking into account the performance of the wind turbine and the availability of the resources was built by Kovács, Erdős, Viharos, and Monostori (2011). Parikh (2012) proposed a mathematical model to optimise the maintenance cost of wind farms by scheduling preventive maintenance and replacement of critical components. An optimal preventive maintenance scheduling model for minimising the overall downtime energy losses was studied by Zhang, Chowdhury, and Zhang (2012). The model takes into account weather conditions, crews, transportation, and tooling infrastructure. A model for the preventive maintenance scheduling of power plants including wind farms was proposed by Perez-Canton and Rubio-Romero (2013), which aims to maximise the system reliability.

2.2.2. Corrective and condition-based maintenance

There are several papers that study scheduling of corrective and condition based maintenance operations. An opportunistic maintenance optimisation model taking into account wind forecasts and corrective maintenance activities was studied by Besnard, Patriksson, Strőmberg, Wojciechowski, and Bertling (2009). Besnard, Patriksson, Strőmberg, Wojciechowski, and Bertling (2011) extended their previous work by formulating a stochastic optimisation problem that considers uncertainty in weather conditions. Byon, Pérez, Ding, and Ntaimo (2011) used the discrete event system specification (DEVS) to build a simulation model for wind farm operations and maintenance where two different maintenance strategies, namely scheduled maintenance and condition-based maintenance are applied. The results showed that condition-based maintenance yields more wind power generation by reducing wind turbine failure rates. Van Horenbeek, Van Ostaeyen, Duflou, and Pintelon (2012) investigated prognostic maintenance scheduling for offshore wind turbines where the added value of a prognostic maintenance policy was quantified. Camci (2015) studied a methodology to schedule the maintenance of geographically distributed assets using their prognostic information which can be applied for maintenance scheduling at offshore wind farm.

The previous works cited on optimal scheduling of maintenance in this subsection have not considered how to access the turbines