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Review

Maintenance logistics organization for offshore wind energy: Current progress and future perspectives

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ABSTRACT

Logistics and supply chain management of maintenance is a very critical task in the offshore wind energy industry. A failure to deliver proper maintenance services may adversely affect the wind farm availability and thereby reducing power output as well as profitability. The organization of maintenance logistics for offshore wind farms has received a reasonable attention in the literature to date. The purpose of this article is to review the state-of-the-art of maintenance logistics in offshore wind energy. It proposes a classification scheme involving three echelons of strategic, tactical and operational decision-making. The strategic echelon deals with decisions regarding wind farm design for reliability, location and capacity of maintenance accommodations, selection of wind farm maintenance strategy, and outsourcing the repair services. The tactical echelon embraces spare parts inventory management, maintenance support organization, and all decisions regarding purchase or lease of maintenance resources. The operational echelon includes scheduling of maintenance tasks, routing of vessels, and measuring the maintenance performance. Our findings indicate that the strategic decisions of maintenance logistics have received the most attention in the literature, followed by the tactical and operational decisions. Also, three categories of selection of maintenance strategy, maintenance support organization and scheduling of maintenance tasks are the most addressed areas of research.

1. Introduction

Over the last decade, there has been a considerable growth in offshore wind power capacity and the amount of electricity produced is rapidly increasing every year. For instance, the cumulative installed capacity of offshore wind power in the European Union (EU) has increased from 532 megawatts (MW) in the year 2003 to 6600 MW in the end of 2013, which represents an annual growth of about 29% (see Fig. 1) [1]. Presently, the UK with 22 operational offshore wind farms and a total installed capacity of 4,049 MW is ranked as the world's largest producer of offshore wind power. At the end of 2013, the share of offshore wind in UK's electricity generation was 3.3%, while it is forecasted to reach up to 10% by 2020 [2].

Despite the significant growth in offshore wind power capacity, the harshness of the marine environment and rapid changes of weather conditions result in reduced levels of system availability/reliability. Analyses of field data collected from SCADA[1] system show that the availability of onshore wind farms is typically between 95% and 99%, while it is evaluated to be in the range of 60%—70% for offshore wind farms [3]. In addition, the limited availability of supply vessels to transport the heavy spare parts may lead to lengthy lead-times and subsequently, increased operation and maintenance (O&M) costs. For a thorough review on the existing challenges and opportunities in installation, construction, and maintenance of offshore wind projects the readers can refer to Ref. [4].

Currently, the O&M costs constitute a substantial portion of the overall life cycle cost (OLCC) of an offshore wind project. For instance, for a typical offshore wind turbine with twenty-year life span the O&M costs account for about 20%—35% of the lifetime power generation cost [5]. In another report published by the U.S. Energy Information Administration (EIA), the electricity generated by offshore wind turbines is evaluated 2.6 times more expensive than that generated onshore [6]. Therefore, in order to make offshore wind power cost-competitive with onshore wind and also with the other sources of renewable energy, the reliability, availability, and maintainability (RAM) of offshore wind farms need to be significantly improved.

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[1] Supervisory Control and Data Acquisition.

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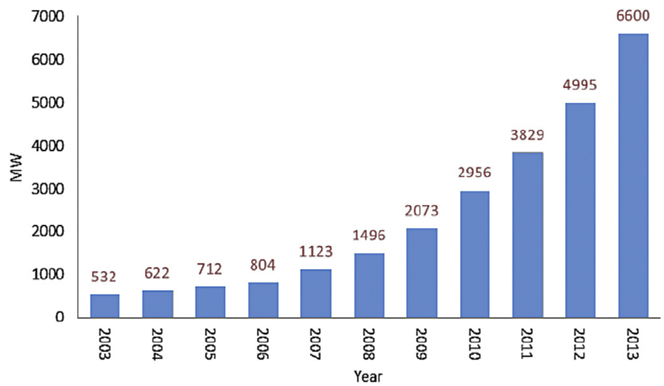

Fig. 1. Total installed capacity of offshore wind power in the EU during 2003–2013 [1].

'Maintenance logistics' is known as an important competitive factor in the offshore wind energy industry having a significant impact on profitability of wind projects. The existing statistics show that the maintenance support expenditures (including the costs of maintenance labor, hiring the service vessels, and ordering the spare parts) constitute a major part of the O&M costs. On the other hand, maintenance support activities (e.g. spare parts supply and distribution) are recognized as major contributors to greenhouse gas emissions from wind power (~10 g CO_2-eq./kWh or equivalently 28% of the total emissions) [7].

Logistics management of maintenance is a very critical task in the offshore wind energy industry. It also becomes more crucial for wind farms located in cold, icy or remote areas where the accessibility for maintenance is restricted [8]. Once an alert signal is detected by monitoring system, a maintenance task is scheduled for the critical or faulty equipment. Necessary spare parts are ordered from wind farm depots; the required transportation means (e.g. workboats and helicopters) and service vessels (e.g. jack-up boats and crane ships) are hired; and a number of maintenance technicians are allocated to preform the repair tasks. Any failure to deliver proper maintenance logistics due to lack of spare parts, unavailability of means of transportation, or insufficient staffing may adversely affect the wind farm availability and thereby reducing power output as well as profitability. For this purpose, a well-organized maintenance logistics is required not only to reduce the O&M costs but also to ensure that power generation matches the demand and greenhouse gas emissions are cut in a cost-effective way.

During the recent years, many researchers and practitioners have shown their interest in the study of *supply chain management* (SCM) for offshore renewable energy (see, e.g. Refs. [9–11]). However, the existing logistics organizations have not been well designed to cope with the 'maintenance challenges' of offshore wind farms, and hence, there still remains a gap between academic models and application in practice. In this paper, we review the state-of-the-art of maintenance logistics in the offshore wind energy industry. The key issues and challenges in the subject area are identified and the published literature is reviewed and analyzed. Moreover, some directions for future research from the point of view of researchers and practitioners are highlighted. To the best of the author's knowledge, this paper is the first review article on "maintenance logistics" since offshore wind energy's inception in 1991.

The structure of this paper is as follows. In Section 2, we present a framework to classify the available literature. Section 3 deals with the strategic issues of maintenance logistics in the offshore wind energy industry. Subsequently, the relevant tactical and operational issues are discussed in Sections 4 and 5, respectively. Section 6 deals with supplementary issues of relevance to the topic. We finally conclude with some comments in Section 7.

2. The classification framework

In this section, we present a classification framework aiming to identify the various issues and challenges associated with maintenance logistics of offshore wind farms. Since the service lifetime of a wind turbine is relatively long (20–40 years) [5], the maintenance logistics organization must be designed in such a way that takes into account the whole life-cycle of wind projects. Our framework is constructed based on a three-echelon architecture, namely the "strategic/tactical/operational" model which is applied to studies of "logistics management" within a wide range of disciplines. The model involves three echelons of decision-making, as described below:

(i) *Strategic (long-term)*: The strategic echelon deals with decisions that have long-lasting effect (i.e., over whole life cycle) on O&M of the offshore wind farms.
(ii) *Tactical (medium-term)*: The tactical echelon typically includes decisions that are updated anywhere between once a year and once every five years (overhaul interval).
(iii) *Operational (short-term)*: The operational echelon refers to day-to-day decisions within offshore wind farms.

In order to make the classification framework, we first needed to identify the main categories that each echelon of the model (i.e., strategic, tactical, and operational) consists of. For this purpose, we reviewed and analyzed the academic works and industrial reports published on the subject area, and also conducted an experts' survey with closed-ended questions. The available literature includes contributions from both scholars and practitioners in scientific journals, conference proceedings, master and doctoral dissertations, text books, and case study reports. At first, our literature search was based on the descriptor 'maintenance' in the offshore wind energy literature, which originally produced around four hundred publications. Then, the full text of each work was reviewed carefully to consider those that only focus on 'logistics' issues. Finally, one-hundred and thirty-seven publications were selected for their relevance to maintenance logistics of offshore wind energy.

The distribution of the publications considered in this study is shown in Table 1. As can be seen, our database contains sixty-nine journal papers, forty-six conference papers, thirteen master and doctoral dissertations, two text books, and seven technical reports. Also, Fig. 2 represents a bar chart showing the number of works by year of publication. As shown, a large majority of the works have appeared just over the last few years. This implies that more publications may be expected to appear in the coming years.

According to the reviewed studies and the survey results, ten "core" and four "supplementary" categories were identified for the subject area. The core categories include: wind farm design for reliability, location and capacity of maintenance accommodations, selection of wind farm maintenance strategy, outsourcing the repair services, spare parts inventory management, maintenance support organization, purchasing or leasing decisions, scheduling of maintenance tasks, routing of maintenance vessels, and measuring the maintenance performance. The supplementary categories are: RAM[2] data availability, O&M costing, tools for forecasting the wind/wave conditions, and information on

[2] Reliability, Availability, and Maintainability.