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Advanced logistics planning for offshore wind farm operation and maintenance activities



Yalcin Dalgic^{a,*}, Iraklis Lazakis^a, Iain Dinwoodie^b, David McMillan^b, Matthew Revie^c

^a Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, 100 Montrose Street, Glasgow, G4 0LZ UK

^b Institute for Energy & Environment, University of Strathclyde, Glasgow, UK

^c Department of Management Science, University of Strathclyde, Glasgow, UK

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ABSTRACT

Offshore wind turbine technology is moving forward as a cleaner alternative to the fossil fuelled power production. However, there are a number of challenges in offshore; wind turbines are subject to different loads that are not often experienced onshore and more importantly challenging wind and wave conditions limit the operability of the vessels needed to access offshore wind farms. As the power generation capacity improves constantly, advanced planning of Operation and Maintenance (O&M) activities, which supports the developers in achieving reduced downtime, optimised availability and maximised revenue, has gained vital importance. In this context, the focus of this research is the investigation of the most cost-effective approach to allocate O&M resources which may include helicopter, crew transfer vessels, offshore access vessels, and jack-up vessels. This target is achieved through the implementation of a time domain Monte-Carlo simulation approach which includes analysis of environmental conditions (wind speed, wave height, and wave period), operational analysis of transportation systems, investigation of failures (type and frequency), and simulation of repairs. The developed methodology highlights how the O&M fleets can be operated in a cost-effective manner in order to support associated day-to-day O&M activities and sustain continuous power production.

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1. Introduction

Wind power industry has continued to grow rapidly in recent years with major developments in offshore wind farms. The availability of large areas in order to locate major projects, the lack of existing limitations associated with visual impact and noise, higher wind speeds, and the lower turbulence levels in the offshore environment have encouraged operators to invest in offshore wind farms. Despite all these advantages, power production from offshore wind is still significantly more expensive than power generation from onshore wind farms. This is due to more complicated foundations, longer electrical networks, installation and maintenance activities that are dependent on vessels, and harsher climate conditions that limit the operability of vessels and subsequently the accessibility of offshore wind farms. Considering the UK with the greatest operating capacity in its waters, offshore wind Levelised Cost of Energy (LCOE) reached £140/MWh in 2011 (The Crown Estate, 2012); whilst onshore wind LCOE is £74/MWh (WindPower Offshore, 2012).

Operation and Maintenance (O&M) is a significant contributor to the LCOE. The Renewables Advisory Board (2010) reported that offshore access related operations including the cost of maintenance dominate the total offshore wind ongoing costs by 84%, whilst other costs such as licence fees, administration, and insurance account for 16%. Current O&M activities in the offshore wind market is valued around £400 M/year and expected to increase to £950 M/year by 2020; simultaneously, around 40% of the offshore wind turbines in the UK are now approaching the end of warranty periods (WindPower Offshore, 2014). During the warranty period, Original Equipment Manufacturers (OEMs) are responsible for all the O&M activities. In the post-warranty period, the responsibility of minimising O&M costs and optimising operations may shift to the owners and the operators.

The focus of this paper is to design and develop a discrete-event simulation model of an offshore wind farm that allows the identification of favourable operating strategies for offshore wind O&M fleets. The aim is to provide decision support to operators trying to manage a portfolio of wind turbines and a fleet of vessels for the mid-term (~5 years) offshore wind O&M planning. The model builds upon the existing literature by considering different climate parameters, failure characteristics of the turbine components and the operational characteristic of the transportation systems. The combination of the various O&M strategies defines a particular scenario, and the

* Corresponding author. Tel.: +44 141 548 4778, +44 141 548 4094; fax: +44 141 552 2879.

E-mail address: yalcin.dalgic@strath.ac.uk (Y. Dalgic).

simulation model developed allows the operator to assess the different strategies and compare them in terms of generated revenue.

The remainder of the paper is structured as follows. Section 2 reviews common procedures, aspects and issues associated with maintenance of offshore wind farms, and existing offshore wind O&M models. The modelling methodology is explained in Section 3. A case study is presented in Section 4 in order to illustrate the developed approach. In Section 5, the results of the case study are evaluated. Subsequently, final recommendations are provided in Section 6.

2. Literature review

2.1. Economic aspects

O&M activities represent a significant share of the ongoing expenses during the lifecycle of the offshore wind projects (Kaldellis and Kapsali, 2013). The O&M costs comprise of labour costs (technician costs), material costs (component cost), transportation costs (vessels and associated cost), fixed costs (port, insurance, bidding, etc.) and potential revenue losses. In this respect, it is important to identify the critical aspects that can significantly reduce overall costs. It has been identified that the costs associated with transportation systems account for 73% of the total O&M costs (Dinwoodie et al., 2013; Fingersh et al., 2006; Junginger et al., 2004; Krohn et al., 2009). In addition, Van Bussel and Zaaijer (2001) demonstrated that the cost of lifting operations using a vessel accounts for more than 50% of the overall O&M costs. Therefore, O&M activities have to be planned carefully, considering the fact that economic benefits from producing more energy by increasing the availability does not always lead to higher profits, since the increase in the total O&M costs may not be compensated (Dalgic et al., 2015b; Santos et al., 2013).

2.2. Transportation systems

The main tasks of the transportation systems in a maintenance operation are to provide accommodation for crew and technical personnel, loading, transporting and assembling failed turbine components in the offshore environment. During the operational span of an offshore wind farm, a number of scheduled and unscheduled maintenance tasks have to be performed in order to keep the turbines operational and to sustain power generation. In this respect, there are two main categories of O&M vessels in the offshore wind energy market: vessels for minor maintenance and vessels for major maintenance.

Regarding vessels for minor maintenance, current transportation methods to offshore wind turbines include mostly the use of small workboats which involves long shuttling journey times resulting in considerable wasted technician time (Dalgic et al., 2015a; Dalgic et al., 2015c). Monohull boats, small catamaran vessels and Small Water-plane Area Twin Hull (SWATH) vessels are generally utilised in minor maintenance operations, which allow operators to keep the costs at acceptable levels. Catamaran configurations are often the preferred choice but operations are restricted to relatively low wave heights (Tavner, 2012). Access and O&M of offshore wind turbines are severely impacted by very poor weather tolerance, particularly in further offshore locations (Walker et al., 2013). In some cases, operators consider a helicopter in the O&M fleet in order to provide access when the crew transfer vessels (CTVs) are not able to sail due to rough met-ocean conditions. Both transportation systems (CTV and helicopter) involve significant amount of costly and inefficient travel for technicians; in addition relatively small vessels pose a significant risk of capsizing in rough weather conditions (Al-Salem et al., 2006).

In addition to conventional CTVs, Offshore Access Vessels (OAVs) are occasionally considered by the offshore wind operators

in their O&M fleets. These larger vessels (~50 m) have better operational capability than conventional CTVs and are generally equipped with dynamic positioning systems. Additionally, motion-compensating gangways are typically installed on OAVs in order to transfer technicians on the wind turbine in rough weather, in which CTVs cannot operate (Dai et al., 2013; O'Connor et al., 2013). Cranes on these vessels provide ability to transfer medium weight components from vessels' deck directly to offshore wind turbine platforms. OAVs are designed to stay in the offshore wind farms longer periods and therefore the travels between the sites and the O&M ports are minimised. These advantages make OAVs an adequate candidate for the offshore wind O&M activities. However, the charter cost of these vessels is higher than CTVs, which is a major issue considering the fact that the operators intend to minimise the O&M costs. The generic criteria related to human performance are well established for seamen but not so well established for O&M technicians (Wu, 2014). In addition, quality and duration of sleep are impaired by disturbance associated with ongoing tasks and environmental factors (e.g. noise, shared cabins, poor air quality) in offshore environment; and therefore has adverse effects on day-to-day performance and alertness of the O&M technicians (Anderson and Horne, 2006; Belenky et al., 2003; Parkes, 2010; Townsend et al., 2012). Moreover, the use of OAVs is not well defined due to immaturity of the industry. Therefore, OAVs are not considered as a permanent solution like CTVs; instead, these vessels are chartered for shorter periods.

In the case of blade, generator, gearbox or tower failures, small maintenance vessels are not adequate to perform the replacement of damaged components. Instead, one of the jack-up, leg-stabilised or heavy lift vessels has to be utilised considering the properties of damaged component (height, weight, etc.) and the capability of the vessel (lifting capacity, operational water depth, etc.). Jack-up vessels are capable of raising their hulls over the sea-surface, station their legs on the sea floor, which provides very stable environment for crane operations under rough sea conditions. Leg-stabilised vessels are very similar to the jack-up vessels. Instead of lifting the hull over the sea surface, leg-stabilised vessels, which are ideal for operations in shallow sites, use their legs to stabilise the hull. However, the number of leg stabilised vessels is considerably low in the market (EWEA, 2011). Heavy lifters are capable of lifting extensive loads, which can be experienced in offshore wind industry; on the other hand the charter rates of heavy lifting vessels are excessively high (Dalgic et al., 2014; DNV, 2011). Therefore, jack-up vessels are the most utilised vessels for major maintenance operations in offshore wind energy market (Dalgic et al., 2015d).

2.3. Existing offshore wind O&M models

To support operators in optimising O&M activity, different models have been developed to analyse offshore wind O&M activities. CON-TOFAX, developed by TU Delft, utilises Monte-Carlo simulations to analyse state of every component over a period of time (Bussel and Schöntag, 1997). Bussel and Bierbooms (2003) investigated inflatable boats, special offshore transportation systems and helicopters for offshore wind farm O&M activities. The BMT group developed the BMT MWCOST model that considers the significant wave height observations as a limitation for the vessel access (Stratford, 2007), while GL-Garrad Hassan's O2M model, based on work conducted by Bossanyi and Strowbridge (1992), takes the wave height values into account and performs time domain Monte-Carlo simulations (Philips et al., 2006). Other models have investigated integration of remote condition monitoring and fault prediction hardware and software into O&M strategies (Lyrner et al., 2006) or considering corrective maintenance activities and wind forecasting (Besnard et al., 2009). The ECN O&M Tool is generally considered to be the most comprehensive tool for analysing O&M costs and downtime (Curvers and Rademakers,

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