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Exploring the impact of innovative developments to the installation process for an offshore wind farm

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ABSTRACT

For offshore wind to be competitive with mature energy industries, cost efficiencies must be improved throughout the lifetime of an offshore wind farm (OWF). With expensive equipment hire spanning several years, installation is an area where large savings can potentially be made. Installation operations are subject to uncertain weather conditions, with more extreme conditions as OWF developments tend towards larger sites, further offshore in deeper waters. One approach to reduce the cost of the installation process is to evaluate advanced technologies or operational practices. However, in order to demonstrate cost savings, the impact of these advances on the installation process must be quantified in the presence of uncertain environmental conditions. To addresses this challenge a simulation tool is developed to model the logistics of the installation process and to identify the vessels and operations most sensitive to weather delays. These operations are explored to identify the impact of technological or operational advances with respect to weather delays and the resulting installation duration under different levels of weather severity. The tool identifies that loading operations contribute significantly to the overall delay of the installation process, and that a non-linear relationship exists between vessel operational limits and the duration of installation.

1. Introduction

1.1. Problem context and background

The European offshore wind industry continues to expand, and there is currently a transition towards larger sites with more generating capacity in order to capitalise on economies of scale (European Wind Energy Association, 2013). In some cases these sites will be completed over several phases, and when complete will comprise hundreds of turbines (Renewable UK, 2014). To accommodate these massive turbine arrays, developments are moving further offshore into deeper water (for example from approximately 8 m depth to over 70 m depth) and harsher weather conditions. New operational challenges arise as developments move from smaller coastal sites, less than a few kilometres offshore, to larger offshore sites that can be over 100 km from land. These changes pose additional difficulties due to the scale of offshore operations and the increased exposure to more extreme environmental conditions. With limited industry experience to identify good practice guidelines for these large offshore developments, the levelised cost of offshore wind energy is comparatively higher than other energy sources (Ove Arup & Partners Ltd., 2011), and there is pressure on the industry to improve cost efficiencies throughout the lifetime of an offshore wind farm (OWF).

Installation and logistics have been identified as areas where substantial cost reductions can be achieved through innovation (Offshore Wind Cost Reduction Task Force, 2012, European Wind Energy Technology Platform, 2014). One route to promote innovative developments to the installation process is to improve the understanding of the economic impact of technological and vessel capabilities on an installation schedule. This enables novel designs for installation vessels and techniques to be validated, and developments in operating capability to be directed such that maximum reductions to the installation costs are achieved.

The vessels employed to install the first OWFs were often recruited from the oil and gas industry. The high demand for these vessels would result in high day-rates, while the capability of the vessels would often exceed the requirements for the OWF installation projects. As the OWF market has increased, the reliance on

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oil and gas vessels has reduced and purpose-built OWF installation vessels have become more commonly used.

The demand for specialist OWF installation vessels continues to grow, with various vessels built and commissioned recently (see for example Offshore Wind (2014a, 2014b, 2014c, 2015b, 2015c)) and demand is expected to continue to grow over the coming years (Offshore Wind, 2015a). In a small number of cases, proposed designs for specialist OWF installation vessels have been significantly novel (see for example the Wind Turbine Shuttle (Huisman, 2013), the Windlifter (Ulstein, 2013) and the Windfarm Installation Barge (Ingenium, 2011)). These vessel designs are generally conceptual, however, and may struggle to achieve the industry backing and demand to support construction.

The trend to date with purpose-built OWF installation vessels has been to develop vessels which are suited to the changing physical requirements of installations. Larger vessels with increased carrying capacity are being developed (Offshore Wind, 2014a, 2014b), which are capable of working with the growing size of OWF assets (European Wind Energy Association, 2015). Furthermore, the vessels developed are capable of operating at the increasing depths required for the next phase of OWF developments. This trend of increasing vessel capacity has been identified by industry and governmental guidance, as a key requirement to support the anticipated growth of the OWF industry in the coming years (Roberts et al., 2013).

One barrier limiting the adoption of novel vessel designs, and similarly novel installation techniques, is a lack of substantive and quantitative evidence as to the practical benefits which could be achieved. This paper presents a methodological framework which directly addresses this problem. A holistic two-stage approach is presented, which can be used to evaluate innovations to installation vessel design and operation, and innovative technological developments to the installation process. The first stage identifies the operations during the entire installation process which are most susceptible to weather delays. These operations can be considered critical in terms of their impact on the efficiency of the installation duration and cost. The second stage explores the impact on the installation process under a scenario where innovative developments were capable of reducing the weather-sensitivity of these critical operations. By targeting the most critical operations, this two-stage approach has the greatest potential to deliver substantial improvements to the overall efficiency of the installation process. It is perhaps worth highlighting that the methods discussed here can be applied to interrogate innovative developments to the installation process which are proposed through any other mechanism. For example, innovative developments which arise through design requirements can be analysed to identify the practical benefits which would be provided. This would provide guidance as to design criteria which should be pursued, and criteria which cannot be expected to provide real benefit.

The methodology presented here can be used to drive innovative developments to the installation of an OWF. Novel concepts can be explored at the preliminary stages of a vessel design, and a realistic assessment of the expected benefits in terms of operation durations and costs can be determined. In a similar manner, new approaches to OWF component design and installation techniques can be evaluated with respect to the impact these will be expected to have on the duration and costs of the installation. By improved understanding of the impact of innovations, the most strategically beneficial can be pursued, which will contribute towards reducing the lifetime costs of an OWF and help to cement offshore wind as a viable energy source.

The remainder of this paper is structured as follows: in Section 1.2 relevant literature on innovative developments to OWF installations is discussed; Section 2 describes the methodology employed here to investigate these developments. In Section 3 a fictional case-study designed to be representative of the next phase of European OWF developments is utilised to explore the impact of weather delays, and the impact on these delays is investigated as potential improvements to the critical operations are considered; some conclusions and discussion are provided in Section 4.

1.2. Relevant literature on innovations in the installation of offshore wind farms

The traditional approach in the design of new vessels is to identify the requirements of the vessel in its anticipated role, and to devise a vessel design which addresses these requirements, as exemplified in Offshore Marine Technology (2013a, 2013b). Gaspar et al. (2012) provide an overview of advances in ship design, and present an approach to handle various aspects of complexity in the design of an offshore supply vessel. Boulougouris and Papanikolaou (2013) present an approach for the design of naval vessels which incorporates the risk with respect to flooding as an objective in the design process.

Roberts et al. (2013) outline an approach which focuses on the anticipated needs from OWF installation vessels to be developed in the coming years. In their analysis of the supply chain requirements to support the growth of the offshore wind industry to 2030, they discuss the key OWF assets and the means by which these are installed. The requirements of OWF installation vessels anticipated over this period is discussed, with focus on the physical suitability of vessels with respect to the changing size and depth requirements of OWF sites.

Perveen et al. (2014) provide a recent review which covers the various stages throughout the lifetime of an OWF, from planning through to decommissioning. At each stage they discuss the expected technological, ecological and policy-based developments, and discuss the associated challenges. With regard to technological advances in the OWF installation process, there is currently much interest in the development of floating turbines (Perveen et al., 2014, European Wind Energy Association, 2013), which allow deployment of OWTs in waters too deep for economical installation of fixed foundations. Another area receiving much attention is the development of new types of fixed foundation structures to support the wind turbine, particularly for intermediate depth waters, with novel simplified jacket structures and gravity bases attracting particular interest (European Wind Energy Association, 2013). These new concepts are still in development and testing, however, and market ready floating turbines or novel jacket designs are not expected in the near future (Roberts et al., 2013, European Wind Energy Association, 2013).

To the authors' best knowledge, there are few methodologies and software specifically aimed at evaluating installation logistics for an OWF, and to support in the planning of installation operations. Improving the installation process has been identified by the European Wind Energy Technology Platform as a key area for development in order to achieve the lower cost of offshore wind energy required for competition with conventional energy sources (European Wind Energy Technology Platform, 2014). As outlined in Section 1.1, this capability is essential to provide an assessment of the practical benefits gained from any innovative developments to the OWF installation process. One tool with relevance in this area is the decision support system presented by Lange et al. (2012). This simulation tool models the construction of an OWF from the manufacturing of components through to installation. A high-level view of the entire installation process is obtained, and key stages in the manufacture and supply network which could lead to bottlenecks can be identified. The wide scope of this tool necessitates a relatively simplistic model of the installation