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ROBUST INSTALLATION PLANNING OF OFFSHORE WIND FARMS

MASOUD ASGARPOUR*, ASHISH DEWAN*, RENS SAVENIJE*

* Energy research Centre of the Netherlands (ECN)
Westerduinweg 3,1755LE Petten, The Netherlands
Email:asgarpour@ecn.nl,www.ecn.nl

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Summary: *The main risk in the installation of offshore wind farms is caused by unfavorable weather conditions, which can delay the entire installation plan up to several months and hence, increase the installation costs significantly. Currently, there is no study available to model the entire installation procedure of offshore wind farms, considering all the associated delays, costs and risks. In this paper, a generic model for the complete supply chain of offshore wind farms installation is discussed, which can be used for robust installation planning of support structures, turbines and cabling of offshore wind farms, considering delays caused by adverse weather conditions and weather limits of vessels and equipment in far offshore or at the harbour. With this model, it's possible to calculate the costs and delays associated with offshore wind farm installation and thereby, arrive with solutions to mitigate the project risks and reduce the installation costs. This model is in the developing phase by the name of "ECN Install" as part of the Dutch FLOW program [1].*

1 INTRODUCTION

Offshore wind energy is a key pillar of the European energy transition [2]. The European countries are aiming to cover 35% of their energy consumption from renewables by 2020, which sets a target of 40 GW installed offshore capacity by 2020 [3]. By the end of 2013, more than 2000 offshore wind turbines were installed in Europe, making a cumulative total of 6.5 GW in 69 offshore wind farms [4]. Therefore, to reach the ambitious European climate and energy targets, more than 30 GW offshore capacity should be installed by 2020. This means that the required effort for installation of offshore wind farms will be enormous in the coming years. Furthermore, because of environmental laws and limited space near shore, future wind farms will be located in further offshore and consequently in deeper water and harsher weather conditions. Hence, in order to reduce the installation time and costs it is essential to develop robust long term installation planning concepts that can be used by a variety of users such as installation contractors, wind farm developers, harbour authorities and OEMs.

There are several existing Installation models such as the Jobs and Economic Development Impact (JEDI) Model, DOWEC Cost Model, OWECOP II Model, Opti-OWES Model and the FLOW cost model [8,9,10,11]. However, the tools developed are only cost models and don't include the aspects of supply and logistics. Besides that, some contractors have their own logistic software in-house. But then, there is a lack of one software package which can be used by all the parties.

With the model proposed in this paper, the concerned parties involved in the installation of offshore wind farms can share project input and develop one software environment. Thereby giving an opportunity to model the entire wind farm installation with an integrated approach with inputs from all parties.

The planning and installation model being developed can be used for accurate prediction of associated costs, delays, effort incurred and risks while installing an offshore wind farm. In the consecutive sections, the general advancements and challenges of installation are discussed. The model methodology will be explained and sample results with tables and figures are demonstrated for a better understanding. The paper is concluded with a summary of capabilities of the tool and topics of further research for improvement of the working model.

2 INSTALLATION OF OFFSHORE WIND FARMS

The installation of offshore wind farms is influenced significantly by weather conditions. The initial planned timeline might not be valid while undertaking the real implementation of the installation steps. In general, it is observed that support structures can be installed in more adverse weather conditions compared to the blades and nacelle. The installation of the latter requires more reliability of the weather, logistics and working conditions. This implies that planning installation is quite critical for the overall success of the process. Moreover, an actual indication of the date of commissioning and associated installation cost is necessary. Another aspect critical for the successful realisation of the project is the spare part and resource management. For instance, if the capability of the vessel is to transport six piles, it is necessary that the same number are available at the harbour for loading. These small optimisation of resources can highly influence the installation costs and hence mitigate project risk. With larger and far-offshore wind farms planned in future, the efficiency and the reliability of the entire installation process is quite relevant.

2.1 Installation advancements

Installation costs are dominated by vessel and equipment hiring costs. To date, with existing installation of offshore farms, new installation practices are being explored which can impact these costs [8,9,10,11]. Some of these trends are:

1. Use of larger and faster vessels for installation, allowing more turbines to be transported and installed in one trip, thus reducing time spent transporting hardware from manufacturing facilities. An exciting method is the offshore transfer of components from support vessels to jack-up installation vessels, avoiding the

need for these high-cost vessels to return to port to collect another batch of turbines.

2. Pre-assembly of turbines completely on land and thereafter install turbines and foundations in one operation, potentially reducing dependence on expensive vessels. [6]
3. Use of multiple harbours to reduce the transport costs of arranging components and moreover also reduce the travel time from the nearest harbour to the wind farm offshore. [7]
4. To date, installation of subsea cables has been characterised by cost overruns and in a number of cases, cable damage. Subsea cables have been the largest source of insurance claims in offshore wind to date. There is certainly room for savings due to a more holistic consideration of cable design and installation requirements and methods.

2.2 Challenges in planning and Installation of offshore farms

A key concern for many offshore developers is the availability and suitability of installation vessels and the corresponding equipment. Choosing the right vessel is more important having a large vessel [5].

The other potential bottleneck are skills, project management and offshore technicians. It is recognized that different planning strategies can influence installation times and costs.

With the challenges above, an installation model is discussed in the next section to provide a solution for long term planning of installation of offshore wind farms in a thorough way applicable for different installation strategies.

3 GENERIC MODEL DESCRIPTION

3.1 Concept

The objective of a planning system for the installation of offshore wind farms is to reduce the construction time and the project risk, which is proportional to the installation costs. With each additional day, the leasing of vessels, equipment and crew will exceed the initial planned project time and estimated costs. Therefore, to support the process, ECN by using its in-depth knowledge in modeling operation and maintenance of offshore wind farms [12] started the development of the ‘ECN Install’, a software tool applicable for robust installation planning of offshore wind farms. As indicated above, the model can be applied differently by separate users.

The Installation model is a time-domain simulation program being developed in MATLAB and Visual Studio and is designed to assist OEMs and developers of wind farms to determine the optimal installation strategy during the planning phase of installation.

3.2 Properties of Installation Model

The Installation model of the ECN Install provides the user to simulate the proposed plan of installation in the form of 'steps'. In order to have a generic model only three types of steps are considered:

1. Loading step, which describes the set of activities to load the components from the harbours to the vessel;
2. Traveling step, which describes the traveling of the vessels between the harbours and the farm;
3. Installation step, which is used to describe all installation activities being performed with vessels and equipment; e.g. piling or vessel positioning.

Besides the above set of steps defined as an initial plan by the user, general inputs of the wind farm installation like working patterns of the crew, climate information, vessels and equipment used, harbours and turbine data, etc. are also obtained. A screenshot of the interface with vessel inputs is shown in Figure 1.

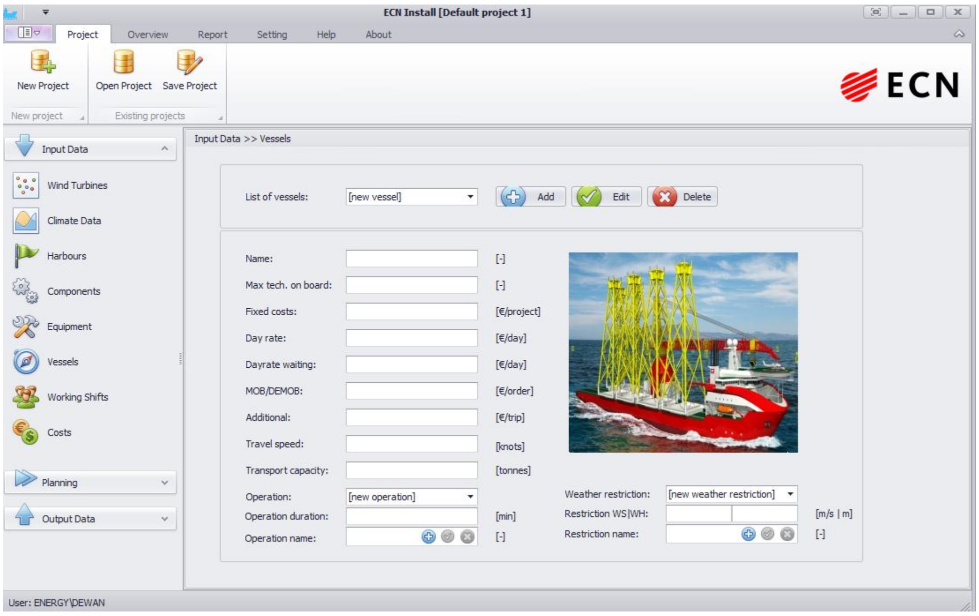

Figure 1: Graphical Interface sample for ECN Install

While defining each of the steps, the user can select the corresponding vessel, equipment, weather thresholds and the components to be installed. The steps are initially processed to compile without any delays. Additionally, the weather information provided by the user is used to create accessibility vectors for performing each particular step. By using a Monte Carlo simulation in the time domain, costs and delays caused by working hours and vessel weather limits are calculated. A working example of the implementation of such steps is described in Figure 2.

In the following figure, an activity termed as pre-piling is performed. In this example, three lines of parallel activities are executed, with each box representing one step. The step could either be loading, traveling or installation.

1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	…	1.n
			2.1	2.2	2.3	2.4			
		3.1	3.2	3.3	3.4	3.5	3.6	…	3.n

Figure 2: Sample Installation of Piles

For instance, step 1.1 could be loading a component to the jack-up barge at the harbour, step 1.2 could be defined as traveling to the farm, and steps 1.3 to the end of the sequence could be vessel positioning, vessel jacking up, placing the template, placing the pile and then hammering. The second line could be a parallel activity like feeding new piles to the jack-up barge with a support vessel and the third line could be an independent parallel activity like installation of balance of plant.

Additionally, it’s possible to cluster a few steps together to use the same weather window. For instance, steps for placing the template and pile could be clustered together to ensure that, during installation the necessary weather window to perform both activities exists. In order to simplify the definition of installation activities it is also possible to repeat several activities, like repeating all piling steps for the number of wind turbines in the farm.

4 RESULTS

The installation model provides an overview of the estimated delays, the time for the completion of each step and the associated costs to complete the installation. The following results and outputs are obtained:

1. Simulation of the installation logistics of an entire offshore wind power plant
2. An overview of:
    i. Breakdown of installation costs
    ii. Breakdown of installation times (planning) and expected date of commissioning
    iii. Breakdown of installation delays
    iv. Breakdown of installation hours for which an equipment is used
    v. Levelized Cost of Energy (LCOE) of installation
    vi. Lost revenues of energy production due to delays
3. Find the best installation solution by optimizing outputs with input parameters
4. Spare part and resource management during the installation process.

A sample output with the breakdown of delays for five steps is given in Table 1. These steps are a combination of loading, travelling and installation steps.

Table 1: Sample Output Table with Weather and Shift Delay

Step No.	Step Code	Step Weather Duration	Step Duration	Step Starting Time	Shift Delay	Weather Delay	Harbour Delay	Step End Time
1	1.1	4	2	50	0	65	0	117
2	1.2	2	2	117	0	0	0	119
3	1.3	12	12	119	7	336	0	474
4	1.4	6	6	474	0	0	0	480
5	1.5	10	6	480	0	18	0	504

It can be easily identified that for each step there is a specific code. For each step with its particular working pattern and weather limits a number of simulations is performed to calculate the delays and associated costs. The corresponding delays, viz. shift delay (due to non-working hours of the crew), weather delay (due to non-accessibility of the wind farm) and harbour delay (due to harbour locks) are obtained. Corresponding to these values, the cost calculations and the effort by the crew are computed and finalized in the form of tables and graphs.

5 CONCLUSION

The model discussed above gives a clear understanding of the installation delays and the relevant costs. Currently, there is no tool addressing the complete long term installation planning. With this model, different users can use this application for various purposes. Some of them are discussed below:

- Developers, investors and financial institutions need to know the costs of installation, date of commissioning and involved risks. Therefore, they are mainly interested in the total installation CAPEX, LCOE and expected date of commissioning. Their risk analysis will be based on the probabilities given to outputs (e.g. 90% chance of value x between x1 and x2). The analysis will take place during the planning phase of the farm.
- Vessel designers analyse the business case of a potential design or make choices during the design process. Therefore, they are interested in the breakdowns of costs, hours, planning and delays. The focus will be on logistics and specifications of equipment. The installation procedures will be of great importance. The analysis can take place during a market study or design process.
- Installation contractors execute the installations and make a plan to estimate the expected costs. Therefore, they are interested in the breakdown of costs, hours, planning and delay. The focus will be on logistics, specifications of equipment and planning. The installation procedures will be of great importance. The analysis can take place during a request of quotation and the planning phase.

- Suppliers deliver the components to the assembly sites or ports. Therefore, they are mainly interested in the required stock over time, besides when and where the component should be made available.
- Harbour authorities want to organise the site to meet the requirements for installations. They are interested in the required stock and cranes over time. The analysis can be done to investigate large investments to further develop the infrastructure of the harbour or to determine the logistics and requirements of the site for a specific project.

With the above list of potential users, the model has great capabilities in bringing the entire wind industry together following an integrated approach. Overall, there are definitely prospective areas which can be combined with this tool to make it really useful for the industry.

6 FUTURE WORKS

In the above sections, the advantage of having a generic long term planning installation model and tool for the growing offshore wind farm industry are illustrated. However, installation is only one component of the entire life cycle cost estimation of the offshore wind farm. Hence, it will be interesting to assess the possibility of integrating the model with wind farm planning and life cycle cost assessment tools. Furthermore, short term decision support models for the daily installation process of offshore wind farms can also be explored.

7 ACKNOWLEDGEMENTS

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