ReaLCoE

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Abbreviation/Unit	Description
CPT	Cone Penetration Test
GE	General Electric Renewable Energy (now GE Vernova Wind)
JDN	Jan De Nul
JUV	Jack-Up Vessel
LCoE	Levelized Cost of Energy
MOI	Marine Operation and Installation
MW	Mega Watt
NZE	Net Zero Emissions
WTG	Wind Turbine Generator

Executive Summary

To achieve Net Zero Emissions by 2050 Scenario (NZE) defined by the International Energy Agency, offshore wind energy is expected to grow rapidly and becomes a major renewable energy source. To consolidate the market position of offshore wind energy, the H2020 EU-Commission Project 'ReaLCoE' studies and enhances the potential of a high-performance 15+MW Next Generation demonstration wind energy converter. This new generation of turbine is intended to deliver electricity at a competitive price without requiring subsidies. The project is split into nine work packages, each one lead by specific project beneficiaries.

The efficiency of the logistic and installation concepts will have a positive effect on the LCoE, which is the objective of Work package 2, 'Development of new logistic-, installation- and marine operation concepts'.

Within Workpackge 2, extensive simulations were performed for the installation of the next generation wind turbines, to investigate and identify the main cost drivers of wind farm installation for different scenarios of wind farms off the coast of Europe.

From these full wind farm installation logistics studies comparing a 6MW and 15MW reference turbine design were carried out. It was concluded that using the higher rated power turbines, or fewer turbines per total MW output, results in better economy of scale, hence lower per-MW installation costs. Because the overall installation duration is significantly shortened and fewer installation weather windows are required, the risk of weather is also reduced. It shall be noted however that this analysis does not yet take into account various issues such as supply chain constraints which occur due to the rapid growth in turbine size, and which can also have a significant impact on installation costs and timings. The latter investigation was obviously not part of the WP2 agreed Scope of Works at the start of the RealCoE project some years ago.

Finally, in Workpackage 2 the overall handling, transport and installation processes were studied. Specifically, the process and relative deflections of the turbine components during offshore installation of blades were modelled with multi-body physics simulations. The theoretical analysis shows that the 15+MW Next Generation turbines can be installed efficiently with the proven concepts and equipment used by GE Vernova and JDN for previous generation of wind turbines. Moving to bigger turbine sizes and deeper water-depth amplifies phenomena generated by the environmental conditions such as oscillations induced by wind and wave loads. To maintain high installation safety and efficiency the equipment and methods need to be upscaled and adapted to the increasing requirements, from e.g. investigations like in ReaLCoE. The concepts for handling and the main equipment such as installation vessel, transport frames and installation tooling are described in this report.

1. Introduction

The following partners contributed to this report (Task 2.4):

- Jan de Nul (JDN, Work Package 2 leader and Task 2.4 leader)
- General Electric Renewables (GE Vernova)
- Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO)

To meet the target of Net Zero Emission of 2050 Scenario and higher demand of renewable energy, offshore wind energy, as one of the main renewable energy sources, are expected to be installed globally in a much safer, more efficient, and more affordable way. To improve the market position of offshore wind energy, the H2020 EU-Commission Project ‘ReaLCoE’ studies and enhances the potential of a high-performance 15+MW Next Generation demonstration wind energy converter. This new generation turbine is intended to deliver electricity at a competitive price without subsidies. The project is split into nine work packages, each one lead by specific project beneficiaries.

Increasing the efficiency of the logistic and installation concepts will have a positive effect on the LCoE, which is the objective of Work package 2, ‘Development of new logistic-, installation- and marine operation concepts’. This work package consists of four main tasks:

Task 2.1: Key assumptions Marine Operation and Installation (MOI) concepts.
Task 2.2: Simulation report for baseline concept.
Task 2.3: Method statements multibody simulation.
Task 2.4: Released report on handling and installation.

Within Workpackge 2, Task 2.2 extensive logistics simulations were performed for the installation of the next generation wind turbines, to investigate and identify the main cost drivers of wind farm installation for different scenarios of wind farms off the coast of Europe, USA and Japan. Foundations were included in the installation logistics simulations, but were not included in the Grant Agreement as part of the WP2.4 deliverable.

Increasing wind energy production will require a reduction in the levelized cost of offshore wind energy. Therefore, wind projects venture into sites with deeper water, increased size of wind turbines, and, consequently, new installation vessels and equipment are also required for this purpose. These trends add both technical and financial challenges to offshore wind farm installation.

For the full wind farm installation logistics simulations (including innovation potential) two reference turbines were selected, a 6MW and a 15MW rating. From these studies it was concluded that using the bigger turbines resulting in “less number of turbines” for a given total MW output is the most dominant factor in achieving lower installation costs. Because the overall installation duration is significantly shortened, and less weather windows are required, and thus less unexpected weather delays occur. It shall be noted however that this does not yet take into account various issues in the supply chain which occur due to the rapid growth in turbine size, and which can also have a significant impact on installation costs and timings. The latter investigation was obviously not part of the WP2 agreed Scope of Works at the start of the RealCoE project some years ago.

Furthermore, the studies found that the maximum wind speed limit and sea conditions for offshore turbine blade installation is another important cost driver and project cost can be reduced if installation wind speed limits are increased, however sensitivity to weather conditions increases with the turbines size. The behaviour of the large 15+MW Next Generation turbine in partially assembled state during blade installation process was analysed in detail within Task 2.3, performing multi-body physics simulations. Relative movements between the top of the tower and the blade during the installation process were investigated.

In Task 2.4 the overall handling, transport and installation processes were investigated. The following chapters summarize concepts for handling and the main equipment such as jack-up vessel, transport frames and installation tooling for the high-performance 15+ MW Next Generation wind turbine developed within the ReaLCoE project.

2. Transport and Installation

Within Task 2.4 the overall handling, transport and installation processes were studied. From the investigation, it was found that the installation of the 15+MW Next Generation turbines can be accomplished applying the proven concepts used by GE Vernova and JDN in the previous wind turbine generation, with a focus on reducing operation risk while increasing efficiency. In other words, the gained experience and the investigations and market trends also determine the investments be done in due time, and thus goes hand in hand and determines the development. Three proven concepts for handling and main equipment such as jack-up vessel, transport frames and installation tooling are described in the following chapter.

2.1. Jack-up Installation Vessel

2.1.1. Introduction

JDN‘s DP2 newly-built jack-up vessel *Voltaire* is capable of installing the 15+MW Next Generation wind turbines as used in the simulations for this project. The vessel’s main specifications are:

- Length: 169.3m (excl. helideck)
- Breadth: 60m
- Max Draft: 7.5m
- Crane Main Hook: 3200t
- Crane Aux Hook: 275t
- Leg Length: 131.5m (98.4m below hull)

More detailed information about the Jack-up Installation vessel can be found back on below link: https://www.jandenul.com/fleet/offshore-jack-installation-vessels

Figure 1: New build Jack-Up vessel Voltaire

Voltaire is capable of carrying five 15+MW Next Generation wind turbines. Jan De Nul's *Voltaire* is recognized as one of the leading vessels in wind turbine installation. Equipped with a 3200-ton crane and boasting a spacious cargo deck of 7000 square meters, the *Voltaire* offers practical solutions for transporting turbine components with ease.

Designed with practicality in mind, the Voltaire's long legs enable it to operate in water depths of up to 80 meters, ensuring versatility in various marine environments. It is capable of transporting either five of the latest 15MW turbines or three of the anticipated 20MW turbines, demonstrating its adaptability to evolving wind turbine technologies.

When designing new vessels, Jan De Nul Group focuses on air quality and climate issues through the intensive treatment of their exhaust gases. Another way to further decrease greenhouse gas emissions is the use of biofuel. *Voltaire* will be able to run on biofuel and the main inpact on greenhouse gas emission is that it can install wind turbines fast and efficient.

Tagline System

The primary function of the tagline system is to control the position and orientation of the lifted turbine component. Especially, when the single- blade installation method is used, it requires accurate positioning to insert the blade bolts into the hub. The tag wire is connected to the yoke and can be remotely operated, so it is possible to control the rotation and position of the lifted component. The tagline system is controlled by an operator positioned on deck and guided by a technician in the nacelle via radio communication. An exampler of the tagline system is depicted in Figure 2.

The system will be mounted to the installation vessel's crane, hence it must be designed and manufactured to fit the specific crane.

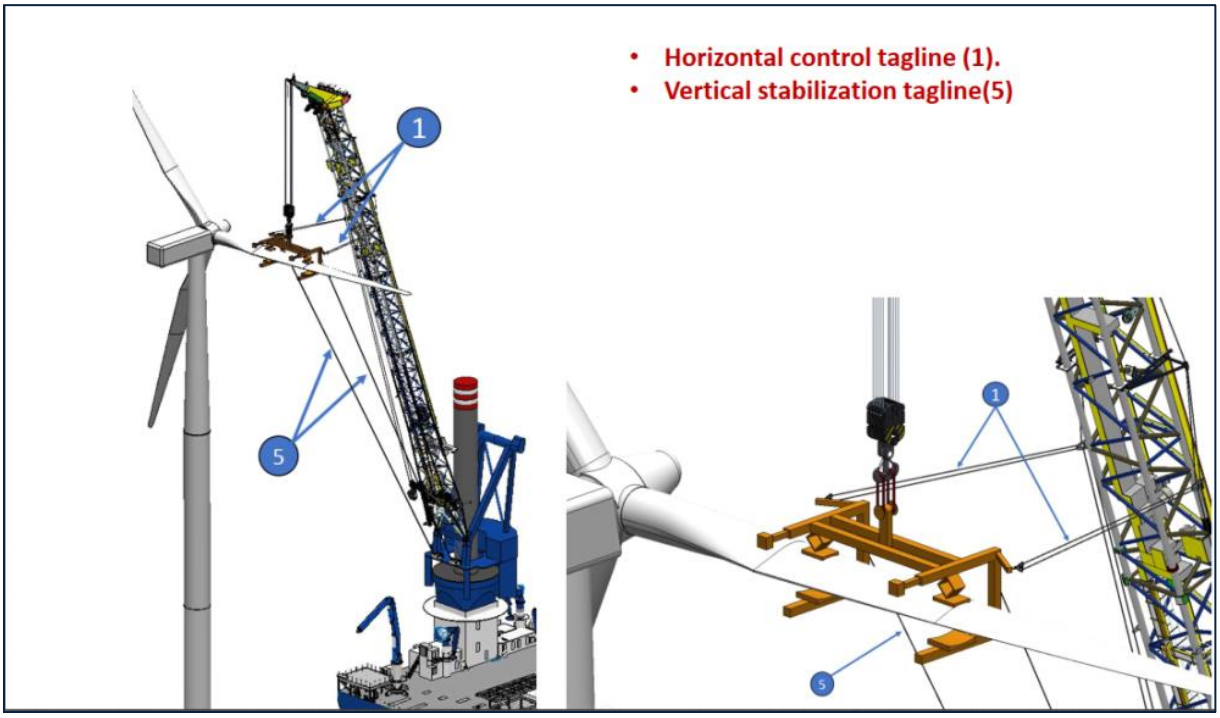

Figure 2: Principle of a tagline system (indicative)

2.2. Wind Turbine Installation

2.2.1. Mobilisation

The marshalling harbour operation and jack-up vessel will be mobilised. Depending on the chosen logistical setup, the preparations for the jack-up vessel will occur either at the marshalling port or at the port from where the vessel is mobilised.

2.2.2. Load-Out

The components will be directly loaded out onboard the proposed jack-up installation vessel. The vessel's main crane will be used to lift the components. The vessel will load all parts at the marshalling harbour. Lifting plans will be prepared during preparation phase.

2.2.3. Tower Onshore Load-Out

The tower sections are transported vertically onboard of the jack-up installation vessel. They will be transported on a dedicated grillage, allowing the sea fastening of the tower sections on the supporting grillage of the jack-up installation vessel. The load-out is accomplished in one piece and with a single lift, from the tower stand at the quayside to the deck grillage of the vessel.

Figure 3: Tower load-out

2.2.4. Nacelle Loading

At the marshalling harbor, the nacelle and its transportation frame are loaded together onboard of the jack-up installation vessel and sea fastened on the jack-up installation vessel deck.

2.2.5. Blade Load-Out

Various solutions exist to position the blades on the deck of the jack-up installation vessel. A typical solution is to load the blades without their transport frames onto a blade rack previously fastened on the vessel deck. The lifting operation for loading blades from the marshalling harbour quayside to the jack-up installation vessel deck shall be done with two cranes, for example by combining the jack-up installation vessel main crane and a shore crane.

2.2.6. Offshore Transportation

Transportation of the components from the marshalling port to the offshore site will be carried out by the installation vessel. A voyage plan supports the bridge team on the installation vessel to ensure that the vessel can navigate safely.

In project preparation, the stability of the vessel for the nominated cargo and deck configuration will be thoroughly checked. For the duration of the project, the first officer will use the on-board computer to verify stability of the vessel under cargo, fuel, and ballast conditions. This is done prior to departure to the wind farm and following each completed installation when the vessel is being prepared to jack-down and reposition at the following location.

Figure 4: Offshore Transport at Doggerbank A

2.2.7. Jacking

After arrival at the installation location, jacking operations will commence. Cone penetration Test (CPTs) at each foundation location with corresponding boreholes and lab tests will be required to make a correct assessment of the jacking operations. The timings of jacking up and jacking down are dependent on the available soil data. Exactly the same soil information is used as for the foundation design, so no additional soil investigation campaign to be done.

2.2.8. Offshore installation activities

Tower Installation Process

Applying the “Full tower installation” concept, the tower sections are pre-assembled onshore on a dedicated foundation on the quay side of the marshalling harbour. This includes the mechanical and electrical completion of this full tower assembly. Following completion, this full tower is loaded-out from the quayside onto the jack-up installation vessel, transported to offshore site for installing onto the transition piece in a single lift.

Tower Lifting tools

To bring tower sections from a horizontal orientation into vertical (upending) the use of lifting lugs is foreseen. These lugs are directly fastened to the tower flanges and removed immediately after installation.

A heavy-duty clamp system with orientation capabilities will be used for load-out and installation lift (tower gripper).

Nacelle Installation Process

The lifting of the nacelle requires the use of a specific rigging arrangement including a lifting tool connected to the nacelle structural connection points. The nacelle is unfastened from its transport frame. The full nacelle assembly of the 15+MW Next Generation wind turbine is connected in a single lift to the top of the completed tower previously installed on the TP.

Nacelle Lifting Tools

The nacelle is lifted using a spreader beam connected to one lift point on the hub and two lift points on the main nacelle body. The design of the lifting tool needs to be as compact as possible to minimize rigging height. Additionally, the lifting tool will incorporate features to facilitate connection with a tagline system.

Figure 5: Nacelle lifting tool

Blade Installation Process

The blade installation process involves the utilization of the blade lifting tool, which is used to grab, orient, and ultimately install the blades on the hub. The blade lifting tool is used in conjunction with a wind turbine rotor turning concept to correctly orient the hub to accept the incoming blade. Rotor turning can be achieved either through gravity force or with mechanical electrical assistance. An illustration of the blade installation sequence is shown in Figure 6 below.

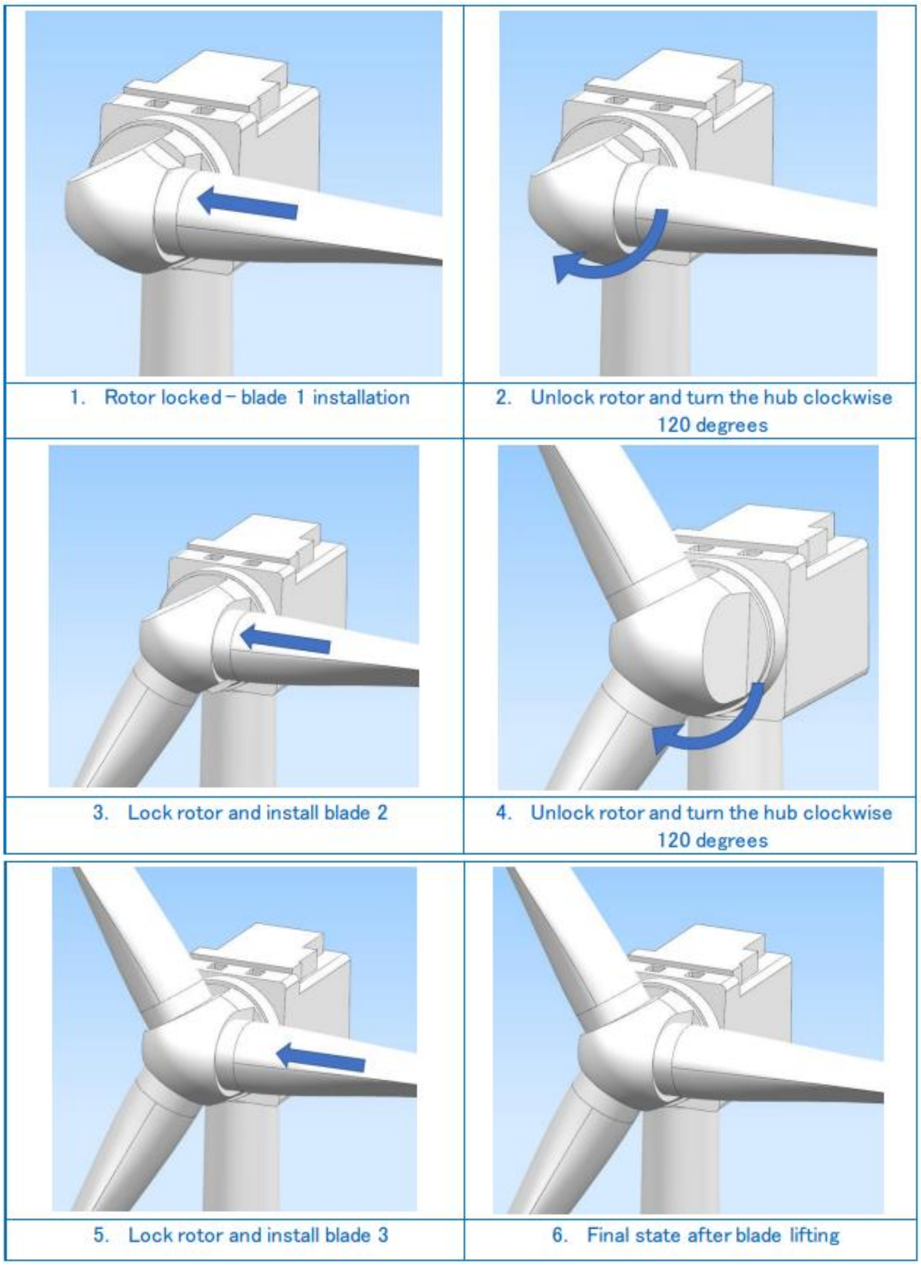

Figure 6: Sequence of blade installation

Blade Connection

The blade flanges come pre-equipped with fasteners designed for insertion into the holes of the pitch bearing located at the rotor hub. Once an optimal number of fasterners are installed and tightened, the blade lifting tool can be released. Any remaining fasteners at the flanged connection can then be tightened after the release of the blade lifting tool.

Blade Lifting Tool

The blade lifting tool is designed to hold, orient, and elevate the wind turbine blade to achieve the blade installation. The tool grips the blade in the vicinity of its center of gravity on dedicated reinforced areas. The blade lifting tool is also equipped with the ability to remotely connect and disconnect to/from the blade. Finally, the tool can be connected to a tagline system to ensure proper control of the blade stability during the lift for blade installation.

Figure 7: Blade Lifting tool for installation

2.3. Assessment for installation of blades

The installation logistics simulations results found that project cost benefits from an increase in maximum wind speed limit for offshore blade installation. For the project specific conditions modelled (EU offshore site), an increase of the maximum allowed wind speed for blade installation by 4 m/s above a baseline value resulted in a reduction of total project cost (including turbines and foundations) and duration as much as 2.5%. However, the maximum wind speed allowed during installation is constrained by various technical issues such as the relative motion of the components during lifting and blade banking, that cannot exceed certain limits which will cause safety hazard as well as an extension of the installation with negative economic impact. It is therefore necessary to carefully balance benefits and downsides when setting this important paramenter.

To further investigate the offshore blade installation process, multi-body physics simulations were carried out within this project. The offshore wind turbine was simulated in a partially installed state. The wind turbine is modelled considering only the monopile, the tower and the nacelle-hub assembly installed (without blades). The movements of the partially installed wind turbine were analysed using the OpenFAST simulation software. In addition, simulations were carried out with Ansys Workbench, in which the movement of the rotor blade hanging on the crane hook was simulated. The relative deflections between the turbine rotor hub and the blade were investigated with increasing wind speed and sea states.

From the simulations, it was concluded that the relative deflections can be lowered by means of an optimized tagline system for blade stabilization and a suitable damping system for the tower. The team also stated that further effects and measures may need to be studied.

Different wind speeds relative to a high wind speed baseline (between 2 m/s below and 4 m/s above) and corresponding sea states were simulated, to analyse the movement of the top of the tower. Figure 8 illustrates the impact of variation of mass of a tuned mass damper (TMD) placed in the nacelle.

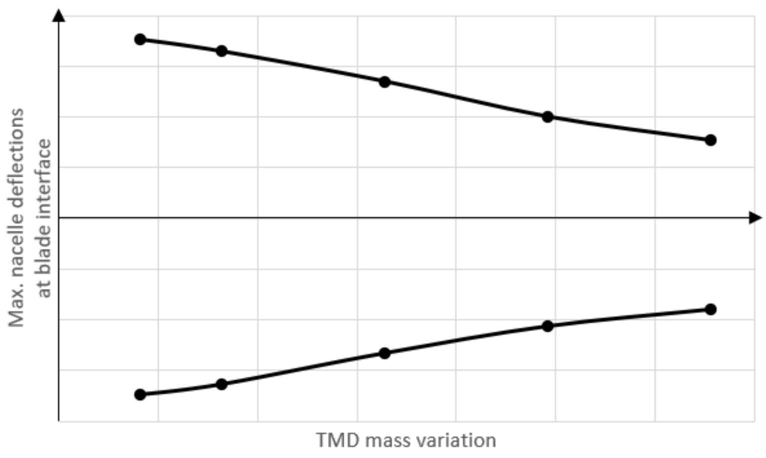

Figure 8: Simulation results for maximum displacements perpendicular to the blade nacelle interface under high wind and corresponding sea states, with varying TMD mass

The optimal damper solution shall be determined, considering nacelle displacements and related installation efforts but also cost and weight aspects of the turbine design.

It is recommended to install sensor boxes to record actual movements of the individual components during blade installation of the demonstration project. This will provide data to validate the simulations results but also provide testing of the measurement equipment itself.

3. Conclusions

This report describes the methods and equipment for handling and installation of the 15+MW Next Generation wind turbines.

From the full wind farm installation logistics studies carried out in Work Package 2 for two reference turbines of 6 MW and 15 MW rating, it was concluded that lower installation costs can be effectively achieved by installing larger turbines reducing the number of turbines per total installed MW. As a consecuence the overall project installation duration is significantly shortened, requiring fewer favorable weather windows and, inherently, also reducing unexpected weather delay events. It shall be noted however that this does not yet take into account various issues in the supply chain which occur due to the rapid growth in turbine size, and which can also have a significant impact on installation costs and timings. The latter investigation was obviously not part of the WP2 agreed Scope of Works at the start of the RealCoE project some years ago.

Furthermore, it was concluded from the investigations on handling, transport and installation processes that the methods and equipment as used on the previous generation of wind turbines can be carried over for efficient installation of the new 15MW+ Next Generation turbines. Moving to bigger turbine sizes and deeper water-depth amplifies phenomena generated by the environmental conditions such as oscillations induced by wind and wave loads. To maintain high installation safety and efficiency the equipment and methods need to be upscaled and adapted to the increasing requirements. The concepts for handling and the main equipment such as installation vessel, transport frames and installation tooling are described in this report.

In this work package the process and relative deflections of the turbine components during offshore installation of blades were investigated with multi-body physics simulations. These investigations concluded that the relative deflections can be lowered by means of an optimized tagline system for blade stabilization, the use of guides and a suitable damping system for the tower.

Leaning on the vast experience and lessons learned from the previous generation is key to de-risking future projects and increasing installation efficiency.