IDL-Tower

Integral Design of Lightweight Tower

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Contact:	T. (Ties) Kerssemakers t.kerssemakers@julesdock.nl

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1 Introduction

Offshore wind energy is a growing market around the world, and is becoming more competitive as energy source compared to traditional sources with each farm that is erected. Not only the increase in number of farms and turbines contributes to this decrease in costs, as innovations are implemented on a large scale. The power output per turbine is passing the 10 MW which also reduces overall costs of a wind turbine farm. Jules Dock, LM Wind Power and TNO started this research to investigate the impact on design, cost, and environment of an offshore wind turbine having a Glassfibre Reinforced Plastic tower instead of a standard steel tower. The technical feasibility of such a design was shown during the C-tower project, and this project is the continuation of the C-tower project. It not only includes the tower, but the monopile foundation, transition piece, and O&M as well, resulting in an integrated design.

Verplichte tekst:
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2 Summary IDL-tower

The IDL-project is a continuation of the previous C-tower research. Jules Dock, TNO (ECN at the start of the project), and LM Wind Power (Knowledge centre WMC at the start of the project) had the aim to design a lightweight tower for the offshore wind industry, by using Glassfibre Composite (GFRP) materials in the tower instead of steel. The result is a reduction in Levelized Cost of Energy (LCoE) of 3.9% for an entire wind farm and reduced environmental impact.

In the C-tower research it was found that a very flexible support structure design, with an eigenfrequency below the 1p range is favourable compared to the traditional design space. To this end the Monopile (MP) and Transition Piece (TP) were optimized simultaneously to have minimal mass and costs.

For the location Borssele 3 and 4 in the North Sea, two different support structures are designed for the 10 MW Avatar Research Turbine. They both consist of a steel MP and TP, where one has a steel tower to be used as reference, and the second the lightweight composite tower. The design and optimisation is done using the Focus6 software. A comparison between the two designs is made on the masses of the components, the Levelized Cost of Energy (LCoE) and environmental impact with a Life Cycle Assessment (LCA).

Material coupon tests were performed using an economical resin. The material properties that were obtained were used in the strength calculations to determine the dimensions of the tower. The expected cost price was implemented in the LCoE calculation and the expected environmental impact of this resin was quantified by LCA.

Implementing a composite tower results in a flexible support structure. It is found that the mass of the steel MP was reduced by 33% and the TP as much as 35% when the composite tower is used. This saves just over 480 ton in steel for the support structure. The weight of the composite tower is reduced to only 41% of the weight compared to the reference steel tower.

To minimize the costs of a composite tower a suitable production method is developed. In continuation of the C-tower project, winding Glassfibers over a mandrel is the method of choice. Several changes to the process are made to improve the technique and make it more suitable for the size and amount of fibre and resin required. The process will be continuous tape winding, a production method in which not the entire tower is supported by a mandrel. This meant that the inner diameter of the tower should be constant over the entire length. This was taken into account in the turbine design as well. Although this shape might not be optimum for weight, the cost reduction in production is believed to outweigh the additional material.

In the project the LCoE was calculated for both turbine designs using the ECN Cost Model. It is found that the LCoE was reduced by 3.9% for a farm using the lightweight composite tower compared to the reference steel tower. The reduction mainly comes from the reduction in material costs due to lower weights, and lower maintenance costs. The actual price difference is €1.66/MWh (€42.97/MWh for the steel tower vs. €41.31/MWh for the composite tower).
Using the SimaPro 8.5.2.0 in conjunction with the Ecoinvent 3.4 database and the ReCiPe2016 endpoint and mid-point, a life cycle Assessment (LCA) was performed on the two different support structures. The impacts on human toxicity are a factor 30 smaller for the turbine with composite tower compared to steel. The difference in embodied energy is negligible, while the carbon footprint for the composite tower is a factor 1.5 smaller. These three impact factors are 33% smaller for the foundations of the composite tower, simply explained by the 33% mass reduction in steel foundation.

3 Purpose of Project

This research has the aim to deliver an integrated design of a traditional steel Monopile and Transition Piece, with a lightweight GFRP tower with the 10 MW Avatar research wind turbine. This design will be compared with a design having a regular steel tower on weight, Levelized Cost of Energy (LCoE), and environmental impact through a Life Cycle Assessment (LCA). The turbine will be designed for the Borssele 3 and 4 locations in the North Sea. This sets the environmental data, a realistic distance to port and shore, and number of turbines to use in the LCoE and LCA. A decrease in LCoE and environmental impact would be a successful design.
A smaller land-based wind turbine is designed with a GFRP tower as well. The 2.5 MW Nordex N80 turbine is used in this design. The location is the Maasvlakte II in Rotterdam. This design can be used in a real life demonstrator and first proof-of-concept for the full scale offshore turbines. The production is realisation of this onshore demonstrator is not within the scope of the IDL project.

4 Methodology

During the C-tower project, a design basis was found for a flexible support structure with an eigenfrequency below the 1p range. This research took off from this point, now also changing the dimensions of the monopile and transition piece. The designs were implemented in Focus6 to verify that the design would not fail. As the location has a significant impact on design choices, the environment of Borssele 3 was used as reference.
With the ECN Cost Model the LCoE of a wind turbine farm was calculated, for both a reference design with steel tower, and the new, lightweight design with composite tower. Borssele 3 & 4 were used as reference farms, having the same amount of turbines and for distances to shore.
The difference in environmental impact was investigated with an LCA using Simapro 8.5.2.0 in cojunction with Ecoinvent 3.4 database.
To reduce the cost of the tower, an economical resin was found and tested on coupon level to determine the material properties. These were implemented in the Focus6 calculation to obtain a realistic design. The material costs were used in the ECN Cost Model.
A production method was developed further to estimate production costs and requirements. These costs are also implemented in the ECN Cost Model.

5 Results

In this research, a 10 MW offshore wind turbine with composite tower is developed, with a mass reduction of 33% in the MP, 35% in the TP, and 59% in the tower. In the MP and TP this meant a total of 486 ton of steel being saved. The tower went from 790 tons in steel to 320 ton of GFRP. The LCoE was reduced with 3.9% for the composite design, dropping from €42.97/MWh to €41.31/MWh.
The LCA showed positive results for the composite version as well, having a carbon footprint of just 66% compared to the steel version. The main reason is the reduced amount of material in the tower and foundation. One disadvantage of the composite tower is the end-of-life stage of the tower itself. Steel was taken to be recycled, the composite waste is expected to be incinerated, generating

electricity in the process. However, with the foundation containing more than double the amount of material the impact of this is small.

6 Possibilities for future work and spin-off activities

The development of composite towers for offshore wind turbines is on conceptual level much further compared to the C-Tower project, in which now the monopile and transition piece are included in the design process as well. It is shown that a mass reduction in complete support structure can be achieved, reducing both LCoE and environmental impact.

The next step would be the scale up of the production, taking into account the challenges identified during the small scale tests in this project. Next to that, a demonstrator project seems a feasible way of convincing the energy market of the feasibility of a composite tower. Jules Dock is actively searching for partners and investors making this scale up in production and demonstrator project possible.

Furthermore, research towards new connection methods is being done in cooperation with the TU Delft. Connecting the composite tower and steel foundation is difficult and old-fashioned bolts will not be the most efficient method.

7 Conclusions and recommendations

The result of the project is an integrated composite tower with monopile foundation, which has a 59% and 33% mass reduction in tower and foundation compared to a steel tower design, respectively. This mass reduction led to a ~3.9% reduction in LCoE on a case study performed on the Borssele III and IV wind farm site. Next to that, the environmental impact of this support structure is lower, mainly due to the reduction in foundation mass.

A potential next step would be a demonstrator model, to show the market the potential of this innovative type of support structure. However, this would require a large investment on this point in the project, for which external parties have to be included.