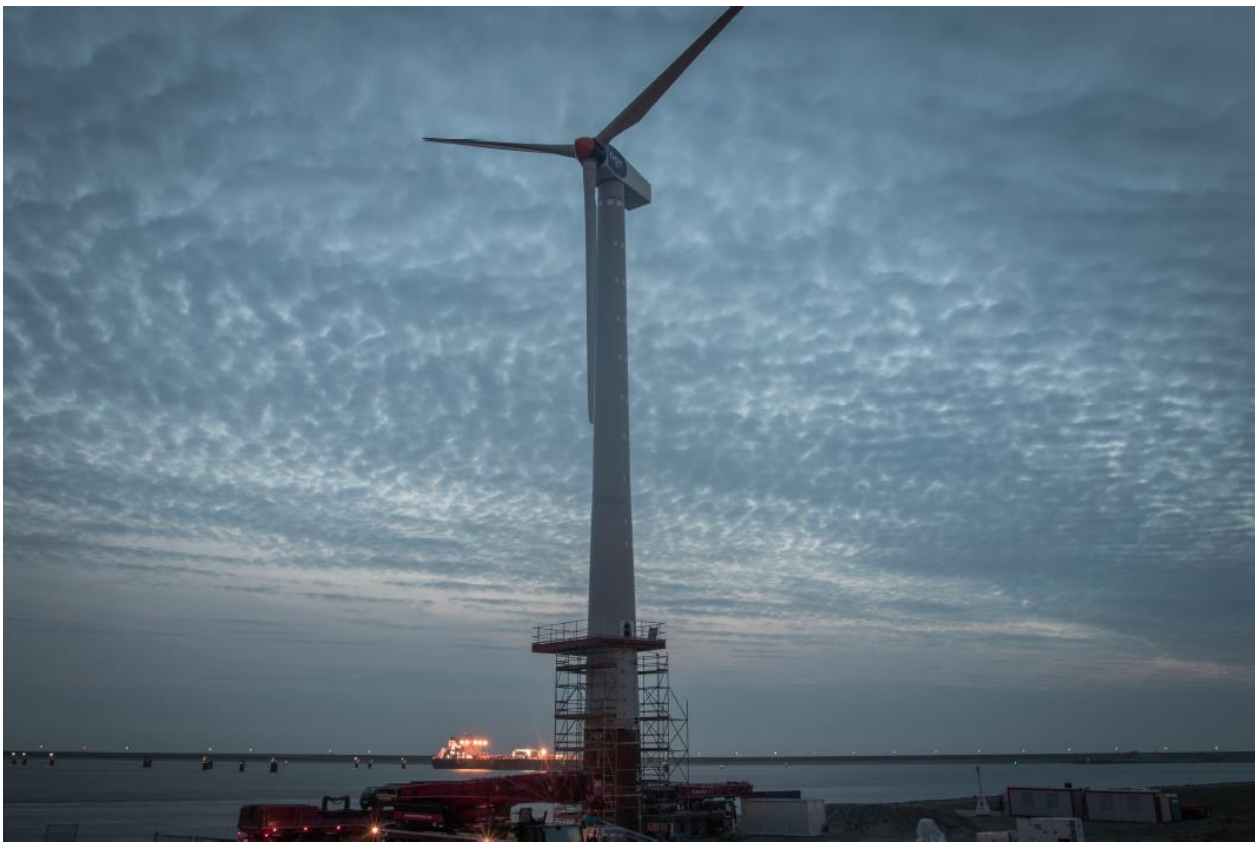
DOT 500 ONT - PUBLIC REPORT

TKI Wind op Zee R&D 2015

Eindverslag over de uitvoering van de activiteiten en de resultaten ervan



Title: Delft Offshore Turbine Onshore tests

Abbreviation: DOT 500 ONT
Project number: TEWZ115019
Program line: 2. Optimisation wind power station
Project period: 01-09-2015 / 31-07-17

Consortium partners:

DOT BV (Penvoerder): Raam 180, 2611WP Delft, the Netherlands
TU Delft: Delft Center for Systems and Control (DCSC)

Project funding:

"Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland."

Ministerie van Economische Zaken

TOPSECTOR ENERGIE
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1. EXECUTIVE SUMMARY

Background DOT hydraulic wind turbine concept

The drive train of horizontal-axis wind turbines (HAWTs) generally consists of a rotor-gearbox-generator configuration in the nacelle. While the HAWT is a proven concept, the turbine rotational speed decreases asymptotically and torque increases exponentially with increasing blade length and power ratings. The increased loads primarily affect the gearbox generator combination, which makes it a maintenance-critical and high-weight component in the turbine. In an effort to reduce turbine weight, maintenance requirements, complexity, and thus the Levelized Cost of Energy (LCOE) for offshore wind, the Delft Offshore Turbine (DOT) concept combines outfitting of individual wind turbines with a hydraulic drive train with a centralised generator system. The main goal and deliverable of this project is a fully commissioned and tested 500kW DOT hydraulic wind turbine.

Project intermediate test set-up and plan

In a collaboration between DOT and the TU Delft, a second hand 500kW Vestas V44 land turbine was retrofitted into a full-scale DOT hydraulic wind turbine. An intermediate concept was implemented, using off-the-shelf components, to speed up development and showcase the practical feasibility of the hydraulic drive train. In this set-up, the rotor is coupled to a low-speed oil pump which is coupled to a high-speed oil motor. The oil motor drives a commercially available high-speed water pump, which in turn drives a Pelton turbine that is coupled to a generator (Figure 1). The hydraulic drive train was modelled theoretically and numerically prior to executing an extensive in-field test plan; using this set-up, two alternative torque control strategies were evaluated and rotor and generator power optimizations were performed.

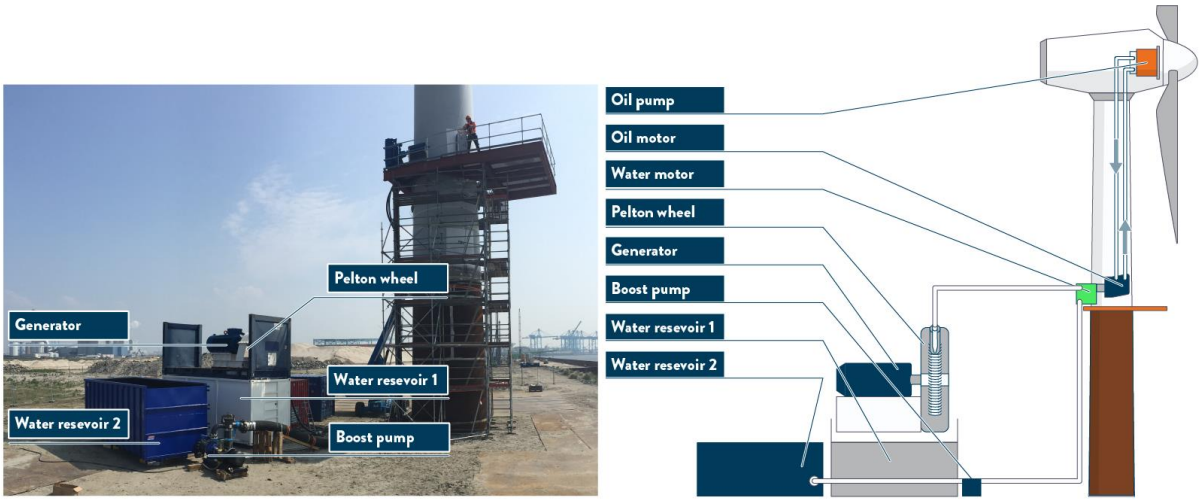

FIGURE 1 | OVERVIEW OF ONSHORE TEST SET-UP

Installation, commissioning and test results

A suitable test location was found on the Maasvlakte II in the Rotterdam harbor area. In a collaboration with Cape Holland, Bonn&Mees, Mammoet and F&B Windpower, both the monopile foundation and the retrofitted turbine were successfully installed (Figure 2) and removed. Prior to the actual on-site turbine installation and commissioning, various safety preparations were completed. Amongst others a FMEA, HAZID, certified training for working at heights and a visit from the *Gezamenlijke brandweer* (GB) on invite by DOT to discuss various safety related issues. In the next phase of the DOT development, the retrofitted hydraulic turbine will be installed offshore. Baring this in mind, a remote-control cabinet was installed, enabling remote system control and monitoring. During turbine commissioning, a supervisory control scheme was developed, together with a turbine fault detection system, enabling safe operation of the turbine under all conditions. Overall, the project was a success: a wind turbine can be controlled by means of a hydraulic drive train connected to a variable nozzle. More detailed conclusions from the in-field test are the following:

- The developed DOT hydraulic wind turbine control strategies proved to be safe and stable over the full turbine operating range
- Active and passive spear valve control are a feasible control substitute for industry standard generator torque control
- Spear valve control enables operation at both the theoretical maximum rotor power and rotor torque coefficient
- Operating the DOT hydraulic wind turbine at $C_{\tau;max}$ instead of $C_{P;max}$ improves overall system power extraction
- Extremum Seeking Control (ESC) is a valuable data-driven method to compensate for errors and optimize performance

FIGURE 2 | COMPARISON BETWEEN DESIGN (LEFT: 3D RENDER) AND ACTUAL TEST SET-UP (RIGHT: PHOTO OF FINAL SET-UP)

Workshops, seminars, courses and publications

At the start of the project, DOT organized a measurements workshop with more than 30 participants from 13 different companies attending. All participants were invited to share their best ideas on possible measurement campaigns on the monopile foundation and the hydraulic turbine. The results from the campaigns, executed by various companies, were presented during a more private seminar. 18 participants from 6 companies listened to 4 interesting presentations and engaged in a discussion on next steps in exploiting the data. Upon project completion, DOT organized an evaluation session with all contractors involved in the installation and removal of the test set-up. The session entailed a detailed evaluation of all preparations, execution and safety related issues in general. Some of the main lessons learned have been incorporated in a guest lecture in a 1-day course Introduction Offshore Safety (IOS), hosted by the DOB-Academy in Delft. An abstract about a specific part of the test results has been approved by the international fluid power conference (IFK). This lead to a conference paper request, which is under construction at the time of writing. The draft of a first journal paper is being developed in parallel, waiting to be submitted to the international scientific journal Wind Energy Science.

FIGURE 3 | IMPRESSION OF EVALUATION SESSION (LEFT) AND MEASUREMENT WORKSHOP (RIGHT)

Next development steps DOT concept

The DOT500 drive train was built with off-the-shelf components using an oil pump in the nacelle. The next step is the development of a dedicated seawater pump that can be coupled directly to the rotor of a turbine and run at low speed (DOT 500 Aqua – TEWZ116036). Following the onshore tests and the development of the seawater pump, the next step in the DOT development is a full scale offshore test. To this end, the Vestas V44 turbine will be outfitted with the dedicated seawater pump, enabling the first prototype without the temporary oil-loop. TU Delft, TNO, van Oord, Sif Group and DOT have combined forces in the Slip-Joint Offshore Research (SJOR TEHE116334) project. This project focusses on the connection between the foundation pile and the wind turbine tower. The objective of this research is to investigate the structural behaviour of the Slip-Joint in offshore conditions during installation and to investigate the critical areas of the Slip-Joint. Next to testing the 500kW machine offshore to acquire operational knowledge of a dedicated water pumping wind turbine, the main development steps for the near future are to develop and test a 3MW dedicated sea water pump and to triple to 9MW as fast as possible towards the first commercial DOT wind farm.