ABSTRACT

Fully-coupled nonlinear time domain simulation results for four tension leg platform wind turbine concepts are compared with results from simplified linear frequency domain analysis to determine the extent to which such fast analyses can be used for optimization. A spreadsheet-based design program was used to generate TLPWT hull dimensions which met baseline criteria. Then, the platform motion, nacelle acceleration, and tendon tension response were computed using a state-of-the-art fully-coupled time domain wind and wave simulation tool. These results were compared to estimations based on the dry mass, linearized mooring system stiffness matrix, first order potential theory hydrodynamic coefficients and environmental conditions. The results indicated that the frequency domain approach can predict trends for the platform motions, nacelle acceleration, and dynamic tension for the wave-only case, but improvements to the linear model may be required to be able to accurately compare the performance of different designs, especially in combined wind and wave conditions.

KEY WORDS: TLP; offshore wind; nonlinear analysis; parametric design

INTRODUCTION

The tension leg platform wind turbine (TLPWT) concept is promising for intermediate water depths, particularly where spar buoys are not feasible, since the limited platform motions are expected to reduce the structural loading on the tower and blades compared to other floating concepts. Although several TLPWT concept designs have been proposed (Matha 2009; Henderson, Argyriadis et al. 2010), and some parametric studies are available, such as (Tracy 2007) (later shown to have errors) and (Sclavounos, Tracy et al. 2007), the accuracy of the linear analysis tools for TLPWTs has not been thoroughly analyzed. Previous work regarding frequency domain simulation of a barge-based wind turbine indicated that good agreement was possible for limited load cases (Philippe, Babarit et al. 2011).

A new parametric study is proposed: first, a simple spreadsheet-based parametric design tool is used to identify four feasible points in the design space; then, those four designs are analyzed using a coupled hydro-, aero-, servo- elastic time domain computer program; and finally, the results of a frequency-domain predictive tool and the more advanced computation are compared. The designs under consideration are single-column TLPWTs with three or four “spokes” or pontoons, intended to support the NREL 5MW wind turbine with the OC3 Hywind tower design (Jonkman, Butterfield et al. 2009; Jonkman 2010). The results of the present work include the prediction of natural periods, response in wave-only conditions, response in combined wind and wave conditions, and a comparison of the generated designs.

PARAMETRIC TENSION LEG PLATFORM DESIGN

Design Parameters

The single-column TLP platform considered here consists of a main cylinder (diameter \(D_1\), length \(l_0\)) continued into a base node (diameter \(D_2\), length \(l_2\)), with overall draft \(T\). Protruding from one of these cylinders are \(n_p\) rectangular or circular pontoons which support the tension legs, as shown in Figure 1. For example, a TLPWT which resembles the SeaStar TLPs (Kibbee, Leverette et al. 1999) with rectangular pontoons (height \(h_p\), width \(w_p\), and total radius from the cylinder center \(r_p\)) and \(n_t\) tendons is depicted in Figure 1a. These pontoons are located at the base of the TLPWT and may provide substantial buoyancy. In contrast, Figure 1b shows another alternative using thin struts with circular cross-section (diameter \(d_p\), and total radius from the cylinder center \(r_p\)) and \(n_t\) tendons. In order to transfer the tendon forces to the hull, additional support wires may be required, but the structural details of these attachments are not considered in the initial design. The vertical location of the tendon attachment point is denoted \(z_c\).

The tendons are characterized by their Young’s modulus \(E_t\), cross-sectional area \(A_t\), initial length \(l_0\), dry mass per length \(\rho_t\), and outer diameter \(d_t\). In general, it is desirable for the tendons to have near zero weight in water, which for typical steel density implies a thickness \(t_t \approx 0.033d_t\).

In order to reduce the number of design parameters, the freeboard to the tower base \((h_t = h_1 + h_2 - T)\) is constant for all designs (10 m). Some permanent ballast may be added to the base node in order to improve the performance or allow greater stability during installation. The parameter \(BF\) is defined as the ballast mass divided by the displaced water mass.

The coordinate system origin is at the center of the single column at the still water level, with \(z\) vertically upward and \(x\) in the downwind direction. The first pontoon or strut is oriented in the x direction.