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Model test of an inverted conical cylinder floating offshore wind turbine moored by a spring-tensioned-leg

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ABSTRACT: *A new 5-MW floating offshore wind turbine moored by a spring-tensioned-leg was proposed for installation in about 50m water depth. Its substructure is a platform of the inverted conical cylinder type with massive ballast weight plate at the bottom. A 1:128 scale model was built for the preliminary engineering development. The model tests in waves and wind were carried out to estimate motion characteristics of this platform in the Ocean Engineering Wide Tank of the University of Ulsan. Its motions were measured and the RAOs were compared. The proposed floating offshore wind turbine showed a good stability and decent responses in waves, wind and operation of the wind turbine.*

KEY WORDS: Spring-tensioned-leg (STL); Floating offshore wind turbine (FOWT); 5-MW; Model test; RAO.

ACRONYMS

CB	Center of buoyancy	RNA	Rotor nacelle assembly
CG	Center of gravity	STL	Spring tensioned leg
FOWT	Floating offshore wind turbine	TLP	Tension leg platform
MSL	Mean sea level	UOU	University of Ulsan
RAO	Response amplitude operator		

INTRODUCTION

Recently, some floating offshore wind turbines (FOWT) have been developed and deployed in deep sea, while a large number of offshore wind turbines with fixed foundations have been installed in water depths less than 50*m* water deep supporting 3~5*MW* rotor nacelle assembly (RNA). The installation of two fixed offshore wind turbines at 44*m* in water depth was made in the Beatrice Wind Farm Demonstrator Project (Wikipedia, 2013).

Several researches on FOWT have been made. Bulder et al. (2002) analyzed a tri-floater platform wind turbine; Lee (2005) studied a 1.5-*MW* wind turbine; Wayman et al. (2006), Sclavounos et al. (2007), Wayman (2006), Jonkman et al. (2009), Jonkman (2010), Jensen et al. (2011) and Wang and Sweetman (2012) analyzed various tension leg platform (TLP), spar, semi-submersible and barge substructures of FOWT. Also a few floating wind turbine model tests have been performed in wind and waves. Hydro Oil & Energy performed a scale 1/47 model test of a 5*MW* spar-buoy floating wind turbine at Marintek's Ocean

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Basin Laboratory in Trondheim, Norway (Skaare et al. 2007). Principal Power Inc. carried out a scale 1/67 model test of a semi-submersible platform, WindFloat (Roddier et al. 2010). In this model test, a disk was used instead of three blades to obtain aerodynamic thrust forces. WindSea of Norway was tested at Force Technology on a 1/64 scale of tri-wind turbine semi-submersible platform (Windsea, 2013). Reynolds scale was used in wind tunnel and Froude scale in basin, respectively. Model tests of OC3-Hywind were carried out at the wide tank, the University of Ulsan (UOU) on a 1/128 scale and the scale model was moored by 3 catenary mooring lines (Shin, 2011) and moored by a spring-tensioned-leg (STL) (Kim, 2011).

To produce electricity with higher efficiency at lower costs in deep sea, however, it is necessary to consider building wind farms with plenty of FOWTs, not a single FOWT. Then, FOWTs should require not only smaller foot prints to prevent mutual interferences among them, but also installation cost lower than those of existing FOWTs.

In this paper, a new substructure of FOWT satisfying both smaller foot prints and lower installation costs in 50*m* of water is suggested to support a 5-*MW* RNA, Jonkman et al. (2009). Its characteristics are as follows:

- An inverted conical cylinder type with heavy ballast weight at its bottom to ensure that center of gravity (CG) is lower than center of buoyancy (CB)
- A tensioned mooring line with a spring to secure small foot print and low dynamic tensions with a quick installation.

Model tests with a 1/128 scale ratio were carried out in the Ocean Engineering Wide Tank of UOU to predict the characteristics of motions of the FOWT platform in wind and waves. Comparisons are made between the inverted conical cylinder in 50*m* of water and the OC3-Hywind moored by a STL at 320*m* deep.

MODEL TEST

Floating offshore wind turbine model

Based on the OC3-Hywind moored by a STL in 320*m* of water (Kim, 2011), the scale 1/128 model of 5*MW* wind turbine with an inverted conical cylinder platform was designed for shallow water applications as shown in Fig. 1. It is a three blade horizontal axis reference wind turbine with 90*m* in hub height. The platform in Fig. 2 consists of two parts. Its upper part is a cylinder to connect to the tower base and its lower one is an inverted conical cylinder with a large ballast plate on the bottom. The inverted conical cylinder was selected for achieving high CB in shallow water and the heavy ballast plate at the bottom was designed for low CG. The large diameter of ballast bottom plate increases yaw inertia of platform. In this platform, CG locates at 23.6*m* and CB locates at 16.9*m* below mean sea level (MSL). The model was moored by a STL. Also a spring case for limited extension of spring was installed inside the platform.

Fig. 1 A FOWT model installed in wide tank.

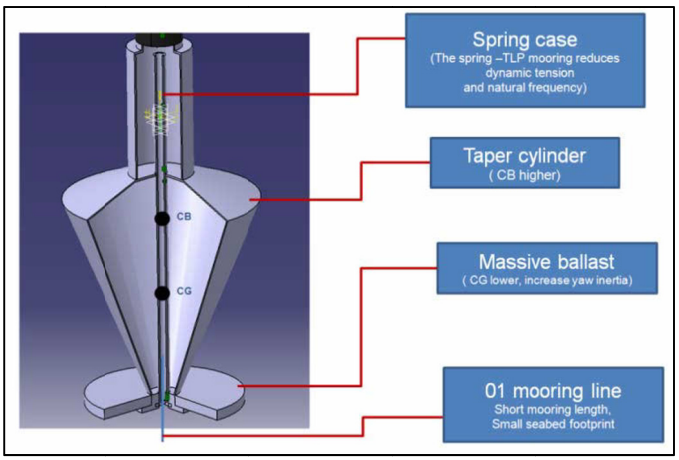

Fig. 2 The inverted conical cylinder type FOWT platform.