Mooring system design for the 10MW Triple Spar wind turbine at a 180 m Sea Depth Location

José Azcona, and Felipe Vittori
Wind Energy Department
Renewable Energy National Center, CENER, Spain

Introduction

This works presents the design of a mooring system for the Triple Spar floating wind turbine that supports the INNWIND 10MW wind turbine.

A semi-taut mooring system configuration, combining steel chain and polyester is chosen to reduce the cost. The basic configuration is defined using static equations. A dynamic analysis for the environmental conditions of the Gulf of Maine, at a 180 m depth location, is performed to verify the performance of the design.

Floating wind turbine model

The Triple Spar platform, shown in Figure 1, is a hybrid design with characteristics of the semisubmersible and the spar concepts. It is composed of three concrete cylinders with a draft of 54.464 m. A steel transition piece connects the platform with the 10MW INNWIND wind turbine. Table 1 collects the main parameters of the floating wind turbine.

Figure 1. Triple Spar geometry

Floating wind turbine parameters	
Nominal power	10 MW
Rotor diameter	178,3 m
Hub height	119 m
Rotor rated thrust force	1500 kN
Platform draft	54,464 m
Columns diameter	15,0 m
Columns distance to platform center	26,0 m
Total mass	29574,3 Tons
Platform mass	28268,2 Tons

Table 1. Parameters of the floating wind turbine

Design methodology

The static catenary equations were used to iteratively reach the adequate mooring configuration. A smooth relationship between the platform displacement and the restoring force is obtained to prevent snap loads during the operation. The curve (Figure 2) also shows that the semi-taut system is able to counteract the rotor thrust force of 1500 kN at rated wind speed and the design extreme wind load of 2050 kN.

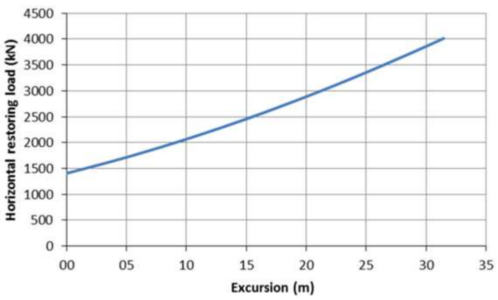

Figure 2. Horizontal restoring load vs. platformdisplacement

Figure 3 shows that the chain segment lays on the seabed connected to the anchor, meanwhile the polyester segment, at the upper part, connects the platform fairlead to the chain.

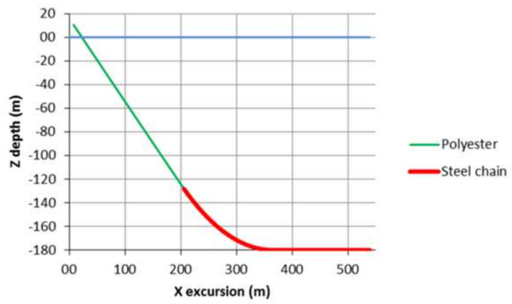

Figure 2. Mooring shape for the undisplaced position

Dynamic verification of the design

The final design of the mooring system ais shown in Table 2.

Mooring system final design			
Number of lines	3	Chain weight/length	6350 N/m
Pretension at fairlead	1700 kN	Chain equivalent diameter	0,324 m
Fairlead position above MSL	10,5 m	Polyester length	239,0 m
Fairlead radial position	33,5 m	Polyester weight/length	240 N/m
Anchor radial position	572,9 m	Polyester equivalent diameter	0,151 m
Chain length	344 m	Polyester axial stiffness	4,32 E4 kN

Table 2. Parameters of the mooring system

A dynamic verification of the design was perform based on a reduced set of load cases, including DLC 1.6, 2.2, 6.1 and 7.1 from IEC61400-3 Ed.1. The extreme tensions and the maximum depth of the connection point between the polyester and the chain are shown in Table 3 and Table 4.

	DLC	Tension L1 (kN)	Tension L2 (kN)	Tension L3 (kN)
Max	6,1	**4139**	1038	2649
Min	6,1	**564**	1048	2062
Max	1,6	1953	**1808**	1938
Min	7,1	3484	**61**	3181
Max	6,1	2757	1078	**4033**
Min	6,1	1885	1050	**446**

Table 3. Extreme line tensions

DLC	Connection depth L1 (m)	Connection depth L2 (m)	Connection depth L3 (m)
6,1	**142,2**	141,3	115,2
7,1	110,2	**165,6**	112,3
6,1	117,0	135,7	**142,9**

Table 4. Maximum depth of the connection between polyester and chain

In addition, natural periods were calculated resulting 166.0 s for surge and sway and 25.5 s for pitch and roll.

Conclusions

The dynamic analysis confirmed the adequacy of the design through the verification of these aspects:

- Maximum tensions are below maximum breaking load of polyester (13172 kN) and steel chain (30689 kN).
- The resulting natural frequencies of the platform are located out of the dominant frequencies of the wave spectrum (4 s - 25 s).
- Maximum angle between water plane and mooring lines is always below 86,7 deg, avoiding the contact between the platform and the lines.
- The polyester segments do not contact the seabed, that could potentially damage them.
- The anchors do not experience vertical loads that could displace them.

A complete load case analysis must be performed to fully validate the proposed design.

Acknowledgements

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No.308974 (INNWIND.EU). We also want to thank Carlos López Pavón and Frank Lemmer for their help and advice.