Numerical Analysis of Three Legged Articulated Tower Supporting 5MW Offshore Wind Turbine

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Introduction

Offshore wind energy is widely recognized as a promising renewable energy capable to satisfy the increasing energy need. Compared to the other renewable energy resources wind energy resource exploitation is becoming more reliable due to technological advancements in the recent past. The offshore wind industry has proved to be a matured one, using bottom fixed support structures. Floating support structure based OWT is becoming more and more technically viable solution for 5MW and higher offshore wind turbine. In contrast to the fixed structures, complaint structures must provide enough buoyancy to withstand the wind turbine weight and also the environmental forces without any substantial displacement. Articulated tower is a compliant structure capable of displacing from its original position when subjected to environmental loads there by reducing the internal response. Developing further on the single leg articulated tower led to the realisation of multi legged articulated tower. The utilization of the universal joint ensures that that the columns always remain parallel to one another and the tower remains in vertical position. This paper highlights with the numerical analysis of a three legged articulated tower which supports an offshore wind turbine to study the motion response of the structure in a given sea state.

Numerical modeling and free vibration studies

The wind turbine and the sea state characteristics are considered as input data. The National Renewable Energy Laboratory (NREL, USA) has made a detailed design of a 5 MW offshore wind turbine (Jonkman et al. 2009). This turbine is assumed to be mounted over three legged articulated tower. The gross properties of the structure are given in Table 1.

Table 1. Properties of the structure.

Total mass of the structure	11232000 kg	Diameter of tower legs	7.2 m
Weight of nacelle assembly	350000 kg	Diameter of upper tower	4.8 m
Depth	144 m	Diameter of supporting beam	3 m
Draft	111 m	Total ballast weight	5175360 kg
Displacement	17947440 kg		

The numerical model of the three legged articulated tower is developed using ANSYS Aqwa. As the dimension of the legs are small compared to the wave length (i.e., for the considered waves diameter of leg is lesser than 0.5 times the wave length), tube elements are used to model the Morison elements in the design modeller of ANSYS Aqwa. Articulated joints are modeled as the joint, which transfers all translational responses. The turbine weight is given as a point mass at the top of the tower. Generated model is shown in Figure 1. The free vibration analysis is carried out and the natural periods of surge, sway and yaw are found to be 37.4 s, 37.4 s and 34.1s respectively. The natural periods of motion for these modes do not lie in the range of typical wave periods, these being from approximately 5 to 17 s.

Numerical investigations

Analysis is carried out in time domain under regular wave in Ansys Aqwa. Equation of motion is solved at each time step. The water particle kinematics is evaluated using Airy's wave theory for the estimation of hydrodynamic forces. Response Amplitude Operator (RAO) of the tower under regular wave loading is obtained in the active degree-of- freedom (surge) and is shown in Figure 2. Analysis under random waves will give the exact behaviour of the structure since the ocean waves are a combination of waves with different frequency and direction. Also the low natural frequency of the structure can be excited by wind loads. So to obtain the actual motion responses of the system, numerical simulations under wind-wave conditions are to be done. Time history analyses are performed under random waves alone and correlated wind and waves are investigated. The wind load on the tower supporting the turbine mass is given by considering a constant wind velocity at 10m height above sea level, which is assumed to be unidirectional and uniform with height. The horizontal aerodynamic thrust of NREL 5 MW wind turbine for operating condition and stop generation power condition are calculated (Zhang et al. 2013) and given as a point force at the top of the tower. The rated speed and cut out speed of NREL 5MW wind turbine are 11.4 m/s and 25 m/s respectively. When at the rated operation point, the wind thrust force reaches the maximum so that the wind-induced loads become most significant under this situation. So the performance of the articulated offshore wind tower subjected to environmental condition corresponding to rated wind speed is investigated. Environmental conditions for the study are Hs=4.55 m, Tp=9 s, U=11. 4m/s; Hs=6 m, Tp=10.28 s, U=25m/s (Oguz et al. 2018). Random waves are represented by JONSWAP spectrum. The wind and the wave are assumed to point along the same direction. All of the simulations conducted were run for 3000 seconds in order to allow sufficient time for the motion behaviour to be captured. For the analysis a time step of 0.1 seconds is used. Responses are compared to realize the effects induced by the wave loads only and the combination of wind and wave loads and are shown in Figure 3 and Figure 4. It is seen that the wind displaces the tower off the mean position where it vibrates.

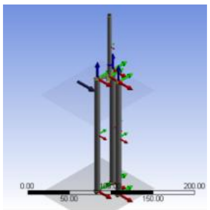

Figure 1. Generated model

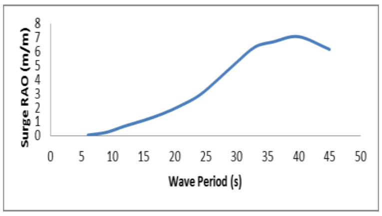

Figure 2. Surge RAO of tower

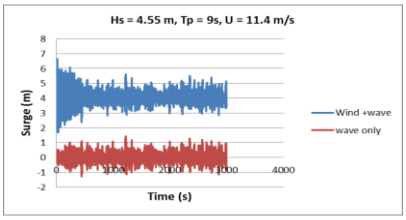

Figure 3. Motion response of tower

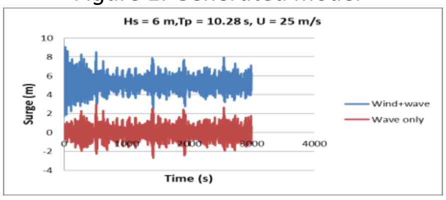

Figure 4. Motion response of tower

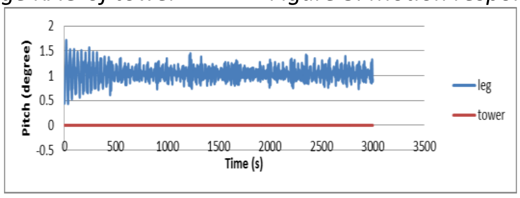

Figure 5. Comparative time history of pitch response

Concluding Remarks

From the analysis it is shown that surge RAO reaches its peak at the corresponding natural frequency indicating less coupling with other modes. The structure suffers only minimum motion response. The pitch response of the tower and the leg (Figure 5) show that response of the tower is lesser than that of the legs. This guarantees that the tower remains vertical under the action of external lateral loads. Reduction in the tower response shall be attributed to the presence of the universal joint between the beam and the legs. The joints confine the transfer of the rotational displacements from the legs to the tower. So the proposed articulated tower is found to be satisfactory for supporting wind turbine.

References

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