ID10 TUNING STRUCTURAL CONTROL DEVICES WITH GENETIC ALGORITHMS FOR A FLOATING WIND TURBINE

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ABSTRACT

Floating offshore wind turbines present several advantages over land-based and bottom-fixed offshore wind turbines, but they are also exposed to strong environmental loads, especially wind and waves, which generate vibrations in the structure and compromise their efficiency and useful life. In this paper, a simplified theoretical model of a barge-type 5MW floating offshore wind turbine is developed and validated with reference software FAST, and used to study the effects of structural control. A tuned mass damper (TMD) is tuned using genetic algorithms for free decay different pitch angles of the platform, which could simulate different heights of waves impacting the turbine, with the goal of reducing the fore-aft tower top displacement. The proposed structural control improves the dynamic response of the system, with a vibration suppression rate of 34.9%.

Keywords - floating offshore wind turbine, structural control, tuned mass damper, genetic algorithms, suppression rate

INTRODUCTION

Although with some clear advantages over onshore and bottom-fixed offshore wind turbines (WT), floating offshore wind turbines still pose significant challenges from the control and stability point of view [1]. Nevertheless, they are subjected to undesirable vibrations caused by strong wind, waves, and tidal loads, and these vibrations must be minimized to increase efficiency and useful life [2, 3].

In this paper, the authors work with a wind turbine model simulated in both, FAST and Matlab/Simulink software, specifically the NREL 5MW WT (three blades, rotor diameter of 12 m and a nacelle height of 90 m) [4]. The floating foundation is the ITI Energy Barge (40 m x 40 m x 10 m and eight mooring lines). The structural control that is applied to the turbine is a TMD (Tunned Mass Damper), installed in the nacelle. This system absorbs energy from the tower’s pitch rotation, reducing vibrations and the displacement of the WT tower top [5, 6]. TMD devices have been proved efficient in reducing the vibrations if the parameters of the TMD are tuned properly, which may be a tedious and difficult task [7]. Because of that, heuristic techniques, including evolutive algorithms, have been used [8,9].

WIND TURBINE MODEL AND VALIDATION

In this work, a simplified model of a FOWT is used, with the degrees of freedom limited to the pitching motion plane of the tower in the downwind (fore-aft) direction. It consists of a system of masses that represent the platform, the tower and the tuned mass damper. It does not consider any other structural components such as blades or mooring lines. With this model, three equations of motions are used, each of them corresponding to one of the three degrees of freedom. All equations are linearized for small angles. From the characteristic equations of the theoretical model, a state space model is built. The spring, damping, and inertia constants can be identified by comparing the outputs of the state space model with the outputs of the high-fidelity FAST model using identical inputs. This process is carried out by means of identification algorithms, the results of which may vary depending on the algorithm, the initial conditions and the simulation time [10].

In this work, the parameters of the model have been identified by the Levenberg–Marquardt algorithm, with different initial inclination of the platform. That is, the different platform pitch angles that are set for the free decay simulation experiments represent the different heights of the waves. The rest of the parameters are known and have been taken from [11]. The model has been identified without TMD. For the validation of the theoretical model, the results obtained by FAST and the previously identified simplified model are compared for a simulation of 100 s, with an initial platform pitch of 5º and including the TMD, with a mass of 20000 kg, damping coefficient 9000 Ns/m and a spring stiffness of 5000 N/m. TMD configuration is the one used by [12]. The mean of the absolute error of the displacement of the tower top (TTDspFA) is 0.042, being considered acceptable.

TMD TUNNED BY GENETIC ALGORITHMS AND RESULTS

Genetic algorithms are applied to optimize the stiffness and damping constant of the TMD. To compare the results obtained with previous works, the size of the mass has been set to 20,000 kg [12]. The fitness function is the Fore-Aft Tower Top Displacement, σTTDFA. Simulations of 100 s have been carried out, starting from a platform pitch of 5º and a null displacement, both of the tower top and of the TMD mass. The genetic algorithm has been configured using an initial population of 75 individuals with two chromosomes (spring constant kTMD and damping coefficient dTMD), with a crossover probability of 0.05*Population, and a mutation probability of 0.01. The generations stop when the average change of the value of the cost function is less than 10-6 during 15 generations.

The kTMD and dTMD values obtained as a result of the optimization are 4868 N/m and 2419 Ns/m, respectively. The responses of the system with the optimized TMD, without TMD and with the reference TMD [12] are compared. The tower top displacement standard deviation (σTTDFA) value is reduced from 0.487 without TMD to 0.317 with the optimized parameters, that is, 35% reduction. The vibrations suppression rate is 28.6% respect to the reference TMD and 34.9% with the optimized TMD (Fig. 1).

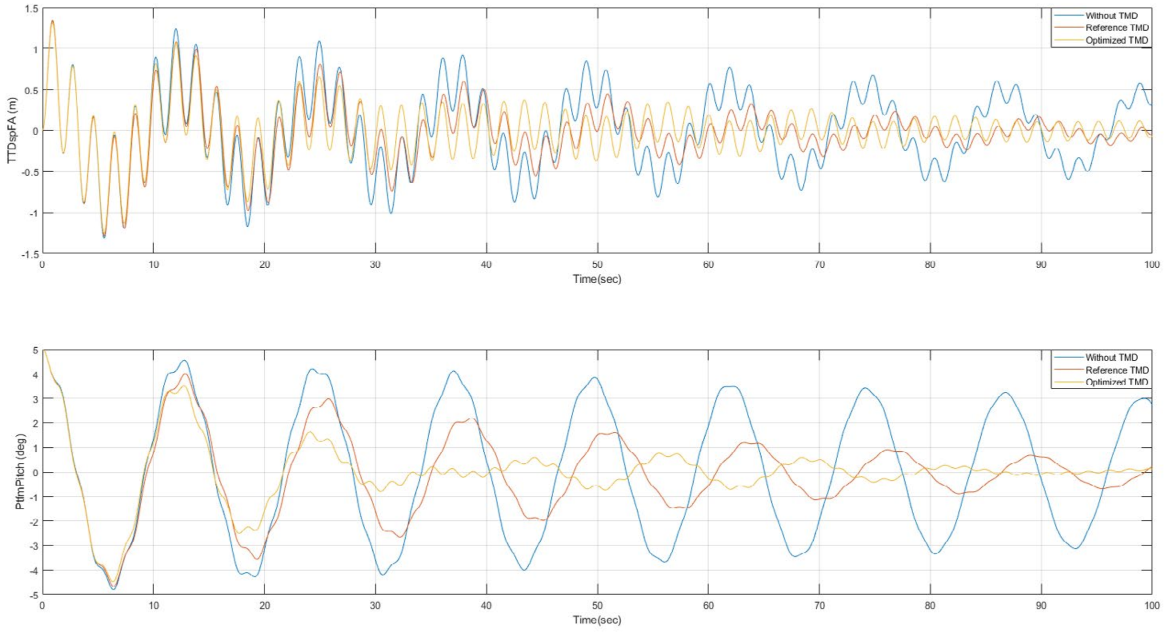

Fig 1. Example of the response of the WT without TMD and with the reference TMD y optimized TMD (platform pitch = 5º). Upper graph: fore-aft tower top displacement; bottom graph: platform pitch angle

CONCLUSIONS AND FUTURE WORKS

The application of a TMD located in the nacelle of a floating wind turbine has a decisive effect in mitigating the vibrations of the tower. The optimal parameters of the TMD must be obtained for different angles of the platform pitch so as to improve the stability of the structure for different initial conditions of this angle, which can simulate different wave heights. This control presents improvements in vibration attenuation compared to other TMDs tuned for fixed initial conditions. The results obtained invite us to study the application of a semi-active control according to the amplitude of the vibrations and consider the non-linearities of the TMD [13] to incorporate external forces, such as the action of waves.

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