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Effective Optimal Vibration Control Methods for Offshore Wind Turbines: Economic and Engineering Perspectives

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Abstract

Offshore wind turbines are subjected to combined wind and wave loadings which causes excessive vibrations on the structure. Vibration control of offshore wind turbines is challenging due to large deformations, self-excited nonlinear hydrodynamic loads and non-linear responses. With the movement of the industry in construction of taller and more flexible wind turbines, the vibration control approaches will play an important role in reducing the vibrations of offshore wind turbines. This paper reviews the vibration control approaches proposed for controlling the excessive vibrations of offshore wind turbines. At first, a general review is provided about the offshore structures including offshore oil platforms and offshore wind turbines modeling. Then, different vibration control approaches are introduced and compared with each other. Finally, the knowledge gaps in vibration control of offshore wind turbines is introduced. Both, fixed and floating offshore wind turbines are considered in this paper. It can be found that the general trend of offshore wind turbines is progressing towards floating type and researchers are mainly focusing on semi-active vibration control of offshore wind turbines.

Keywords: Offshore wind turbines; Vibration control; Active control; Passive control; Semi-active control

1. Introduction

Generally, vibration is objectionable in most structures. Excessive vibrations reduce the fatigue life of the structure, cause fractures, fractures and discomfort, and reduce the efficiency. Different approaches have been introduced to mitigate the vibrations of the structures. However, this paper focuses on the tuned mass dampers introduced to reduce the vibrations of offshore wind turbines.

Offshore structures including oil platforms and wind turbines are subjected to wind and wave loading. The wind effect on the oil platforms is not as significant as in wind turbines. Researchers have focused on controlling, modeling and structural health monitoring of oil platforms [1]–[4].

As mentioned before, the main focus of this paper will be controlling vibration of offshore wind turbines. Different offshore wind turbine types will be introduced initially. Then, various controlling techniques used in the literature to reduce the vibration of the offshore wind turbines will be introduced and compared. Finally, the knowledge gap will be proposed and suggested.

2. Offshore Wind Turbines

In this section, different types of offshore wind turbines will be introduced. Offshore wind turbines are divided into two main categories: fixed and floating. Fixed offshore wind turbines are jointed to the seabed. Floating wind turbines are floating on the sea waves with relative motion between the platform and the sea water particles.

2.1. Fixed offshore wind turbine

As mentioned before, these wind turbines are jointed to the seabed and the relative motion between the structures and the water particles is negligible. The mostly used fixed offshore wind turbines are jacket, tripod and monopile offshore wind turbines which can be seen in Fig. 1.

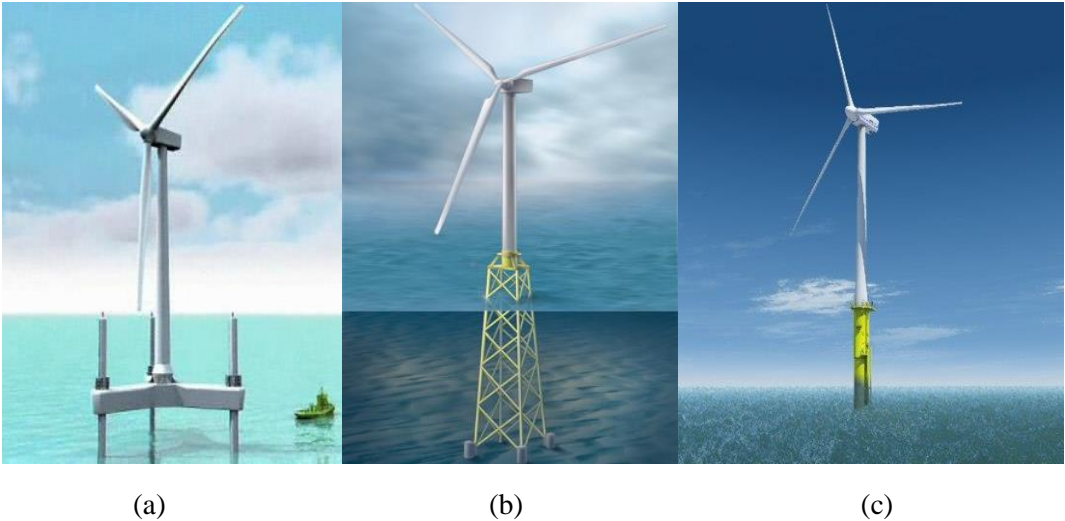


Fig. 1. Different fixed offshore wind turbines: (a) Tripod, (b) Jacket, (c) Monopile

2.2. Floating Wind Turbines

Floating wind turbines are getting more and more attentions recently due to their advantages over fixed offshore wind turbines. Floating wind turbines can be installed far from the sea shores which reduces the visual impact. More importantly, the wind speed is higher and steadier far from the shore. Thus, the floating wind turbines can generate more electrical power than the fixed wind turbines. The most common floating wind turbines are: spar, TLP and barge as illustrated in Fig. 2. Modeling FWTs are more challenging in comparison to the fixed offshore wind turbines due to the relative motion between the platform and water particles. Also, floating wind turbines are larger than the fixed offshore wind turbines. Thus, it is important to consider the flexibility of the components of the floating wind turbines. In this regards, many studies have focused on improving the modeling of these structures [5]–[8].

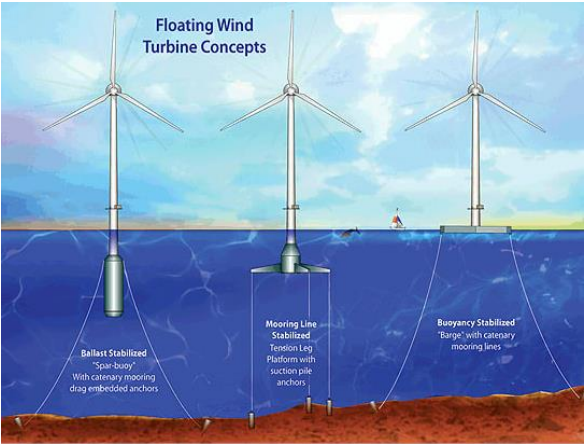


Fig. 2. Different floating wind turbines [9]

3. Vibration Controlling

In this section, the vibration control methods used to mitigate the vibrations of the offshore wind turbines is presented. Generally, three basic control techniques have been developed: passive, active and semi-active [10]. Each of these techniques will be introduced in the following subsections. It should be mentioned that only tuned mass damper controllers are being presented in this paper.

3.1. Passive TMDs

The passive tuned mass dampers do not require any external power source and it only uses the motion of the structure to control forces. These types of tuned mass dampers are used to reduce the vibrations of the blades, nacelle and the platform. Murtagh et al. [11] studied the control of the wind turbine along-wind vibration using a linear mass spring passive tuned mass damper. It was concluded that the response of the wind turbine can be reduced when the TMD was tuned to the predominant frequency. Tuned liquid column dampers are another type of passive TMDs. Colwell and Basu [12] used a tuned liquid column damper to mitigate the vibrations of a fixed monopile offshore wind turbine. The authors also estimated the fatigue life of the structure and concluded that the introduced tuned liquid column damper can increase the fatigue life of the structure. Multiple tuned mass dampers were introduced to reduce the vibrations of the wind turbine blades, nacelle and the platform [13], [14].

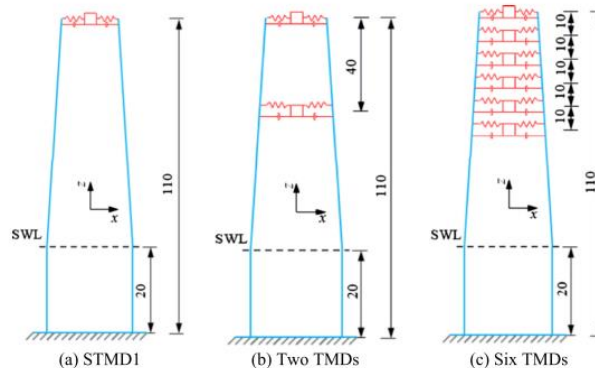


Fig. 3. Different TMD arrangements [13]

The mentioned researches, have considered the wave and wind to be in one direction. Recently, different researches have emphasized the importance of misalignment between wind and wave loading and the significant response of the wind turbine in cross-axis of wind turbine [15]–[17]. In this regard, two linear tuned mass dampers were installed inside the nacelle to mitigate the vibrations of the tower in the fore-aft and the side-side directions [18], [19]. It was shown that the tuned mass damper is capable of reducing the tower fore-aft and side-side vibrations. Also, by reducing the vibration of the tower, the fatigue loads in fore-aft and side-side directions was reduced by 5 and 40 percent. In another research, the disadvantages of two linear TMD were mentioned and a pendulum type TMD was introduced to reduce the vibrations of the tower in fore-aft and side-side directions [20], [21]. The authors concluded that the PTMD is capable of reducing

the response of the tower in both fore-aft and side-side directions and it was shown that the PTMD has a better performance than the two linear TMDs.

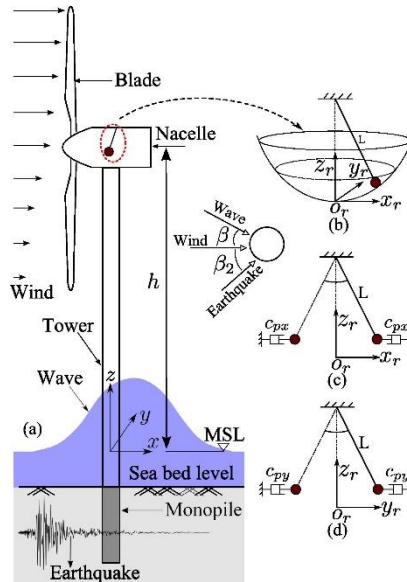


Fig. 4. Pendulum tuned mass damper [20]

3.2. Active TMDs

Active TMDs utilizes external power sources to perform. These TMDs generate control forces based on the sensors and actuators to mitigate vibrations. Lackner and Rotea [22] investigated a passive and active control for a floating barge type wind turbine. The performance of the active and passive control was compared and it was concluded that active control is more effective than the passive control.

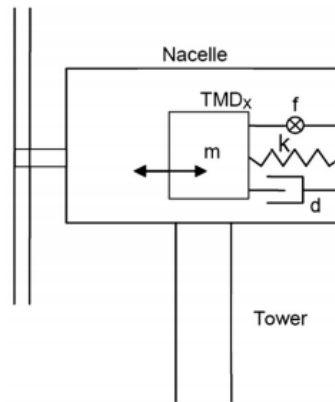


Fig. 5. Linear TMD installed inside the nacelle [22]

Active tendons have been installed inside the blade to mitigate the edgewise vibration of turbine blades [23]. It was shown that the active tendons are capable of reducing the vibrations of the blades. Fitzgerald and Basu [24] used an active TMD to control the in-plane vibration of the blades. Also, the passive TMD was compared and it was shown that the active TMDs have better

performance than the passive TMDs. Active TMDs have been studied in different researches and it has shown promising reductions on the vibrations of offshore wind turbines [25]–[27].

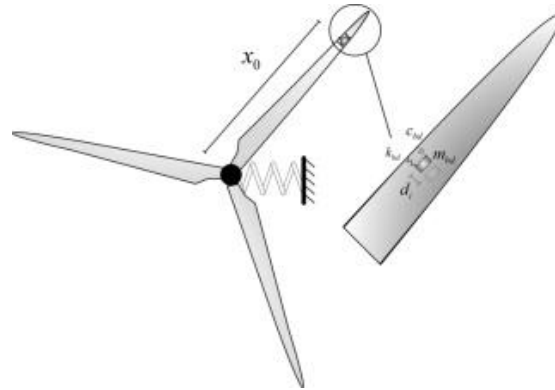


Fig. 6. Installed TMD inside the wind turbine blade

3.3. Semi-active TMDs

Semi-active TMDs require only a small amount of external power to perform. Semi-active TMDs use both advantages of active and passive controlling TMDs to achieve vibration control. Arrigan et al. [28], [29] utilized semi-active TMDs to mitigate the edgewise and flapwise vibrations of wind turbine blades via a short time Fourier transform. It was concluded that the proposed semi-active TMDs are able to reduce the vibrations of the blade in the presence of varying operation conditions. Semi-active TMDs have also been studied to reduce the vibrations of floating wind turbines.

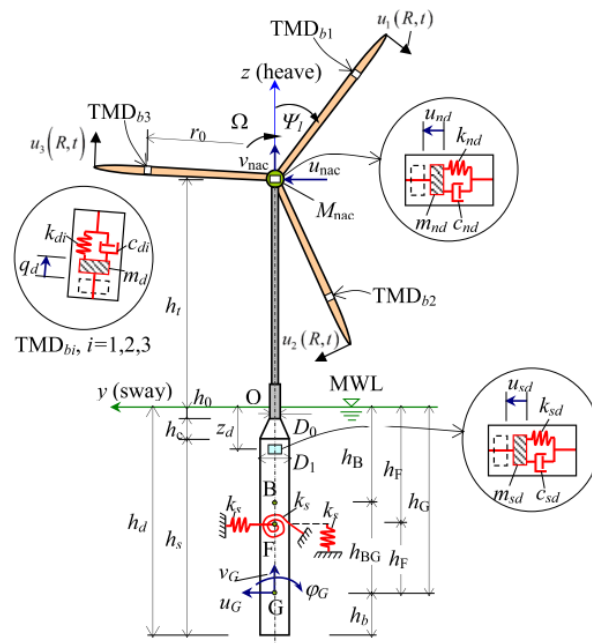


Fig. 7. Schematic model used in Ref. [30]

Dinh et al. [30] installed various semi-active TMDs in different locations to reduce the vibrations of the blades, tower and motion of the platform where the mooring stiffness, rotor speed and the blade's stiffness varied over time. The authors compared the passive TMD with the proposed semi-active TMDs and concluded that the semi-active TMDs perform better than the passive TMDs. Recently, Sun [31], [32] studied the performance of a semi-active TMD on mitigating the vibrations of a monopile offshore wind turbine in the presence of soil effects and structural damage. The performance of the semi-active TMD was examined and it was shown that the semi-active TMD is able to reduce the vibrations of the offshore wind turbine.

4. Conclusion

The excessive vibrations on the offshore wind turbine due to wind and wave loading adversely affects the fatigue life and the productivity of the structure. Considerable researches have focused on reducing the vibrations of the offshore wind turbines. Different controlling techniques have been proposed with different advantages and disadvantages. This paper, provides a review of vibration mitigation approaches for offshore wind turbines.

Three basic control techniques have been developed to reduce the objectionable vibrations: passive, active and semi-active. Each of these techniques have been widely used in traditional civil structures. In addition, some of the mentioned approaches have been used to evaluate their performance in offshore wind turbines.

From the above review, it can be found that more and more researches are focusing on semi-active vibration controlling method due to the advantages of this method over active and passive approaches. A huge gap of experimental research can also be observed in this field.

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