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The effect of actuator dynamics on active structural control of offshore wind turbines

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ABSTRACT

When implementing active structural control in large scale wind turbines, care must be taken to accurately model the dynamics of the actuator in order to develop a robust control system. In this paper, a limited degree of freedom model is constructed, and the effects of both actuator dynamics and control-structure interaction are investigated for an electric motor. The model is analyzed in the frequency domain in order to highlight these effects. The performance of the active control model considering actuator dynamics is compared to previous work in which an ideal actuator was used. It is demonstrated that while loading is reduced for cases that include a more realistic actuator model, greatly increased actuator power consumption makes neglecting control-structure interaction in controller design undesirable. Finally, the impact of the mechanical design of the actuator on control-structure interaction is analyzed. It is shown that by changing the gear ratio of the actuator, the effects of control-structure interaction can be reduced.

1. Introduction

Offshore wind turbines have the potential to be a significant contributor to global energy production, due to the proximity of the high quality wind resource to coastal energy loads. However, due to the addition of wave and current loads, offshore structures must be made stronger, and thus more expensive. The reliability of offshore turbines suffers due to the higher loading, and the inaccessibility of the turbines for maintenance compounds this problem. The ability to reduce loads is therefore extremely important for offshore wind turbines, as it allows for increased reliability and possibly lighter and cheaper structures [1].

One method to reduce loading is to utilize structural control systems, which have been used successfully in civil structures to achieve improved structural response [2,3]. This paper will expand on previous work by one of the authors concerning active structural control for offshore wind turbines [4,5]. It will investigate the important role of actuator dynamics in active structural control applied to offshore wind turbines by using an advanced modeling tool. It will result in a better understanding of the impact of control-structure interaction (CSI) in active structural control systems, and will demonstrate the importance of accurately modeling actuator systems when designing active controllers.

1.1. Previous work

1.1.1. Structural control

For over twenty years, numerous large-scale active and passive structural control systems have been implemented for civil structures [6–11]. These installations employ a range of load reducing devices; the most relevant to this research can be seen in Fig. 1, which shows schematics of passive tuned mass dampers (TMDs), active mass dampers (AMDs), and hybrid mass dampers (HMDs). All three of these variants employ the same concept: displacing a mass in order to reduce the effect of wind and earthquake loading on buildings and bridges. A TMD consists of a mass, spring, and damper that is tuned to a system's natural frequency in order to dissipate vibrational energy at that frequency. An AMD consists of a mass and an actuator, which can be actively controlled to apply a force to the mass and an equal and opposite force on the structure [11–14]. The HMD combines the TMD and AMD, and features both a tuned mass, spring, and damper system as well as an actuator [6,15]. With the addition of an actuator, the HMD gains the potential for improved performance over a passive system. Examples of installed HMDs utilizing servomotor and hydraulic actuators can be found in the literature [3,16]. Both the AMD and HMD can add energy to the system, thus there is a potential for instability. The HMD, however, includes a passive system, so it can still provide load reduction with no actuation power.

Research has been conducted on using passive TMDs for wind turbines, especially for offshore structures due to the larger loading [17–21]. Earlier studies focused on fixed bottom structures,

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