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Adaptation of Controller Concepts for Support Structure Load Mitigation of Offshore Wind Turbines

Binita Shrestha*, Martin Kühn

ForWind, Wind Energy Systems, University of Oldenburg, Ammerländer Herrstrasse 136, 26129 Oldenburg, Germany

Abstract

Different controller concepts can be employed for the support structure load reduction of offshore wind turbines, however, they entail unfavorable collateral effects like additional actuator wear or load fluctuations in other turbine components. Hence, there is a need to identify possibilities of employing such controller concepts only under particular loading and operational conditions e.g. sea states with high waves or large wind-wave misalignment when their load reduction potential is high in relation to their unfavorable side effects. This paper introduces a multi-objective optimization method to perform a trade-off analysis between the reduction of damage equivalent fatigue loads at the monopile support structure and the collateral effects of the different controller concepts. The optimization is performed considering the baseline controller, plus tower fore-aft controller to reduce the tower fore-aft bending moment and the active generator torque controller to reduce the side-to-side load. These two concepts increase the pitch activity and drive train torque variability as collateral effect, respectively. With the optimization methodology presented, it is possible to identify the most efficient operation time to activate different control concepts under each load case, utilizing their advantageous load reduction while limiting their penalty in collateral effects.

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Keywords: Support structure load; controller collateral effects; offshore wind turbine; trade-off analysis; multi-objective optimization

1. Introduction

Support structures can account for more than 36 % of offshore wind farm costs [1], partially due to the aerodynamic and hydrodynamic loads produced by the offshore environmental conditions. There are several active control concepts available for load mitigation [2][3][4] in the wind industry, which can reduce effectively the loads in the support structure, while encountering collateral effects of higher loads in other components of the turbine. As a consequence the wind turbine lifetime could be reduced and an increase in unscheduled maintenance might occur. While the potential for reducing support structure loads due to the implementation of different load mitigation concepts has been already analyzed by several researches [4][5][6], Fischer presented a methodology to employ certain controller concepts at particular loading and operational conditions [7]. Furthermore, Fischer evaluated, at least qualitatively, the

* Corresponding author. Tel.: +49-441-798-5063 ; fax: +49-441-798-5099.
E-mail address: binita.shrestha@forwind.de

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	Support structure		Rotor-nacelle assembly								
	Fore-aft	Side-to-side	Blades	Hub	Yaw	Gearbox	Pitch drives	Additional ULS check	Energy yeild	Power fluctuations	System costs
Tower Feedback Control	↓	→	↗	↗	↗	↗	↗		→	→	→
Active Idling Control	↘	→	↗	↗	↗	↗	↗	●	→	→	→
Individual Pitch Control	↗	↓	↗	↘	↘	→	↑	●	→	→	→
Active Generator Torque Control	→	↓	→	↓	↘	↗	→		→	↑	→
Soft cut-out	↓	↗	↗	↗	↗	↗	↗	●	↑	↗	→
Semi-active mass damper	↓	↓	→	→	→	→	→	●	→	→	↑

Fig. 1. Qualitative fatigue load influences of dynamic control concepts [7].

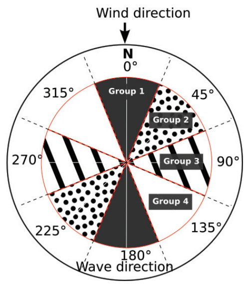

Fig. 2. Wind-wave misalignment groups, with wind coming from the North. The groups are formed merging opposite wind and wave directions.

collateral effects of certain load mitigation concepts on other turbine components, which is illustrated in Fig. 1. Firstly, it can be seen that while quantifying the load reduction at a particular hot spot is straight forward, the evaluation and judgement of the various collateral effects inside the whole turbine system is a rather complex task. Secondly, for the reduction of certain load components, e.g. support structure side-to-side response, more than one option might be available, such as individual pitch control and active generator torque control. However, the collateral effects of such concepts could be quite different, both in magnitude and where they occur within the turbine system.

Few research [8] has been performed to implement the controller concepts not only to reduce the support structure loads but also to limit the collateral effects in a more rational manner. The objective of this paper is to introduce a methodology to approach the trade-off analysis between the reduction of damage equivalent fatigue loads in the support structure and the collateral effects due to the employment of different controller concepts at an exemplified and simplified reference case. A multi-objective optimization method is introduced and performed for the controller activation, considering tower fore-aft controller (TFA) to reduce the tower fore-aft load and active generator torque controller (AGT) to reduce the side-to-side load. The collateral effects considered are increase in pitch activity and drive train torque variability, respectively. Such a multi-objective optimization is regarded as a key element of a more comprehensive system for adaptive operational control, where both sea state conditions and turbine load response is monitored online in order to select the most effective load mitigation controller concepts with respect to a trade-off between load reduction and collateral effects. A brief outline of such a system is discussed in Section 4.

2. Methodology

The hydro-servo-aeroelastic simulation is performed for the 5 MW UpWind [9] turbine on a monopile support structure with the first tower eigen frequency of 0.28 Hz. In this section, the environmental conditions, controllers and other parameters selected are briefly described, and finally the methodology for the trade-off study is explained.

2.1. Environmental condition and sea state lumping

The numerical simulation is set with reference to the external conditions derived from the K13 met-mast located in the Dutch North Sea at 25 m water depth (MSL) [10]. The high hydrodynamic excitation of the relatively soft monopile support structure at deep water locations can be quite sensitive to the wind and wave misalignment. This is because the high aerodynamic damping during the power production mode is acting only in the fore-aft rather than the side-to-side direction. Hence, up to 30°wind-wave misalignment, the loading on the monopile at the seabed can be maximum in the fore-aft direction while the higher loads can occur in the sideways direction for larger misalignment [7][11]. Because of this effect, sea states with different wind-wave misalignments are considered in this exemplary investigation. Meanwhile, only one mean wind speed of 14 m/s with 14.4 % turbulence intensity is taken into account, while the full operating range of the wind speed would be considered in the future extension of this research. Four