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Correlation between Acceleration and Drivetrain Load Effects for Monopile Offshore Wind Turbines

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Abstract

This paper investigates the correlation between the tower-top axial acceleration and the load effects in drivetrain components in a monopile (bottom-fixed) offshore wind turbine. In designing offshore wind turbines, it is a common practice to set a limit for axial acceleration. The main objective of this work is to evaluate the rationality of this assumption as a design criterion for critical components in the drivetrain such as gears and bearings, and to provide guidance for designing the drivetrains in monopile wind turbines. In this study, a 5-MW offshore wind turbine on a monopile structure is modelled and the load effects in the drivetrain are calculated through a de-coupled analysis approach. For each chosen wind speed, the most probable significant wave height and period was chosen from a site in the North Sea with water depth of 29 m which is similar to Dogger Bank wind farm. The results reveal that the life of components inside the gearbox are not correlated with the maximum axial acceleration for the monopile structure. The load effect or life of the first main bearing in the 4-point support is directly correlated with the wind speed while the second main bearing, which carries the axial loads is uncorrelated. The tower-top bending moment, which is an important parameter in designing the main shaft, is found to be highly correlated with the wind speed, not necessarily with the axial acceleration.

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Keywords: wind turbine gears; axial acceleration; drivetrain; monopile

1. Introduction

Offshore wind turbines in Europe have been rapidly developing with a 200% increase in installed turbines in the first half of 2015 compared with the same period in 2014 [1]. Today the International Electrotechnical Commission (IEC) design code 61400-3 [2], "Design Requirements for Offshore Wind Turbines", covers the basic design requirements, while the gearbox design is addressed by the IEC 61400-4 [3]. While it is not explicitly specified in the design codes, there is a common practice in the industry to set a limit for the maximum axial acceleration on the tower-top in the range of $0.2g$-$0.3g$, in particular for the floating wind turbines. There is, however, a question whether this limit is rational.

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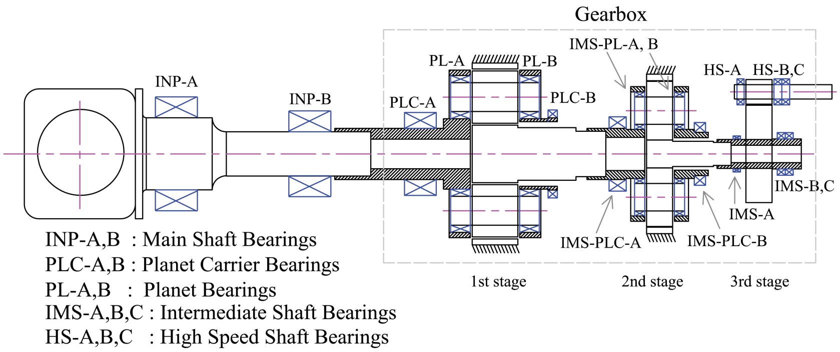

Fig. 1: Layout of 5 MW reference drivetrain [11].

The structural response of the offshore wind turbines have been evaluated in many earlier studies (e.g. Andersen et al. [4] for monopiles or Bachynski and Moan [5] for a floating turbine). The drivetrain local responses have also been studied (e.g. by Xing et al. [6] and Nejad et al. [7]). However, the influence of the axial tower-top acceleration appears to be not investigated in these earlier studies.

In this study the effect of tower-top maximum axial acceleration on the drivetrain installed on a monopile offshore wind turbine is investigated. Monopile wind turbines are installed in shallow water and are subjected to both wind and wave loads. In this study, the NREL 5-MW reference offshore wind turbine [8] is modelled on a monopile structure. The de-coupled analysis approach is employed. The global analysis is first carried out (using the SIMO-RIFLEX-AeroDyn simulation tools [9]) for chosen environmental conditions with an operational turbine. For each chosen wind speed, the most probable significant wave height and period were chosen from the "North Sea Centre" site from the MARINA platform project [10] with water depth of 29 m. This depth is similar to the Dogger Bank wind farm, which has depths from 15 to 36 m. For each environmental condition, 6 simulations, each 10 min., are carried out.

Second, the forces/moments and motions obtained from the global analysis are applied on a detailed multibody (MBS) drivetrain model, for some of the environmental conditions. The 5-MW reference drivetrain is used [11] and the load effects on gears and bearings are obtained.

2. Wind Turbine & Drivetrain Model

The wind turbine under consideration is the NREL 5 MW reference turbine [8], supported by the monopile foundation from the OC3 study [12]. The water depth in the simulations is taken to be 20 m, consistent with the monopile design. The modelled structure is shown in Fig. 2a in Section 3.2. The pile end is 56 m below the still water level (SWL), while the hub-height is 90 m above SWL. The first fore-aft natural frequency of the complete structure is 4.08 s.

In this study, the 5 MW reference offshore drivetrain [11] was used. This is a 3-stage, 4-point support drivetrain with two main bearings and two torque arms. The two main bearing configuration significantly reduces the non-torque loads which enter the gearbox [7]. Figure 1 shows the layout of the drivetrain. The first main bearing (INP-A) carries the radial load while the axial load is supported by INP-B. The first and second stages are planetary spur gears and the third stage is parallel helical gears.

The general specification of the gearbox is presented in Table 1.

3. Methodology

3.1. Environmental Conditions & Load Cases

The wind and wave data from the "North Sea Centre", site 15 in Li et al. [10] was chosen for the analysis. This site is suitable for monopile foundations with an average water depth of 29 *m*, and the location is close to the Dogger