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Tower load analysis of offshore wind turbines and the effects of aerodynamic damping

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Abstract

This study presents an analysis of the loads on offshore Horizontal Axis Wind Turbines (HAWTs). The aerodynamic loads are estimated using the Blade Element-Momentum (BEM) theory, including the effects of dynamic inflow and dynamic stall. The wave loads are calculated using Morison's equation. Models are proposed to account for the effects of aerodynamic damping on the fatigue loading on the tower during its working lifetime. Load analysis of a 5 MW offshore HAWT is carried out and the influence of aerodynamic damping on the fatigue load is investigated.

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Keywords: Offshore wind turbine; Aerodynamic damping; Wave load; Dynamic response; Fatigue load

1. Introduction

In recent years, wind power technology has seen rapid development due to a significant reduction in its operating cost. Currently, wind power has reached a global capacity of 433 GW and for the past 5 years increased in installed capacity by 13-21% each year [1]. The emerging problem is that in some countries the best onshore locations are no longer available, and there is considerable public opposition to a significant increase in onshore wind power installations. Exploitation of the huge offshore wind resource, with considerably less environmental impact than large onshore wind farms, offers a possible solution to the problem of providing for future green energy needs [2].

Although offshore wind resources are of better quality and more abundant, the more severe environment

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demands additional design considerations for offshore wind turbines to ensure safe operation. One important problem is the combined effects of wind and wave loading. To accurately estimate the loading during the lifetime of an HAWT, the effects of damping should be included in the calculations, because damping directly affects the structural response [3]. The damping of an offshore wind turbine consists of a combination of structural damping, soil damping, hydrodynamic damping and aerodynamic damping. Among these, aerodynamic damping plays a key role in restraining vibrations [2-5]. As damping has an important impact on the fatigue damage, research is required to gain more knowledge of the aerodynamic damping effects of offshore wind turbines and to enable accurate lifetime load prediction.

In this study, aerodynamic damping models are presented to incorporate the time-domain load analysis of offshore Horizontal Axis Wind Turbines (HAWTs). Through simulations of a 5 MW offshore HAWT, the influence of aerodynamic damping on the lifetime fatigue load on the tower are investigated.

2. Offshore HAWT tower loading

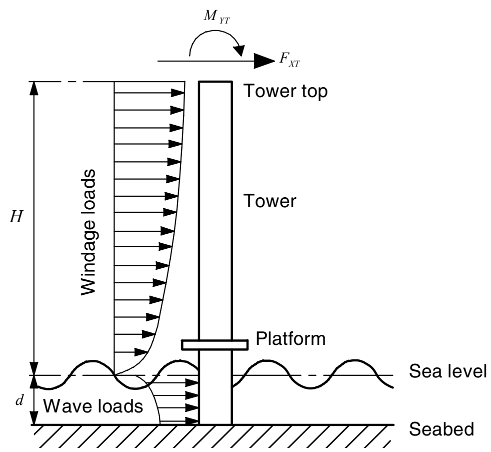

Fig. 1. Loads acting on an offshore HAWT tower.

An offshore HAWT with a tubular tower installed on a monopile foundation was considered. The HAWT tower usually has a large aspect ratio and can be treated as a cantilever. Therefore it can be discretised using two-node beam elements [6] in the finite element model. For an offshore HAWT, the major components of the loading exerted on the tower (see Fig. 1) are the wave loads, the windage loads, the tower self-weight, and the loads acting on the tower top from the rotor and nacelle including aerodynamic and gravitational loads. The aerodynamic damping provided by the rotor mainly affects the tower response in the fore-aft direction and is negligible in the side-to-side direction [2]. Therefore, in the following sections, only the loads affecting tower deflection in the fore-aft direction are analysed.

Aerodynamic loads of the wind turbine blade were calculated using the Blade Element-Momentum (BEM) theory [7]. As the BEM theory was originally developed for a wind turbine operating in steady wind, it was amended by introducing the 'dynamic inflow' [8] and 'dynamic stall' [9] models to account for the transient aerodynamics caused by wind turbulence, yawing, rotational speed regulation and pitch regulation, which are common to a wind turbine operating in the field [10].

The hydrodynamic loading on offshore structures is made of several components, including viscous drag loading, inertia loading, dynamic pressure loading, etc. [2]. If a loaded member is small compared with the water wavelength, the water particle motions are only locally affected by the member and the forces can be calculated from the drag and inertia components using Morison's equation [11]. In this study, the diameter of