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Springing Response of a Tension-Leg-Platform Wind Turbine Excited by Third-Harmonic Force in Nonlinear Regular Wave

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The springing response of a tension-leg-platform wind turbine (TLPWT) excited by the third-harmonic force of an extreme regular wave is investigated using an integrated (aero-hydro-mooring) numerical model developed and presented in this paper. The numerical model comprises a hybrid hydrodynamic model, which employs fully nonlinear potential theory for wave kinematic prediction and non-diffracting potential theory for wave force prediction, to simulate extreme wave and predict associated wave forces accurately and efficiently. Numerical simulations are carried out for the interaction of a floating TLPWT with waves. The focus is on the TLPWT motions, principally excited by the higher-order harmonic wave forces. In particular, the springing response at the triple wave frequency of a regular wave is investigated, together with the wind turbine response and the tensions in the mooring lines.

INTRODUCTION

As per the IEC TS 61400-3-2 (2019) standard, floating wind turbines are designed to survive 50 years of environmental conditions during their 25 years of service life. For a tension-leg-platform wind turbine (TLPWT), operational and extreme wave loads can induce high-frequency resonance and transient responses, e.g., springing and ringing, which may greatly amplify its global responses and reduce its fatigue lifetime. As TLPWTs are designed to avoid resonance by linear force at the dominant frequency f_{wa} of the wave spectrum, they are likely to get excited by the nonlinear force at nf_{wa}, where $n = 2, 3, \ldots$ It is then evident that the springing is principally due to the higher harmonic component of the nonlinear wave force. Thus, in the present work, we shall consider the springing behavior of a TLPWT excited by the higher-order harmonic force of a regular wave. Although the regular wave may not truly reflect the stochastic nature of the real sea state, the results obtained can provide some insight into the springing behavior of the TLPWT.

In the past, extensive efforts were made to improve the understanding of the springing of offshore platforms used for oil and gas exploration. The Norwegian Petroleum Directorate and the UK Health and Safety Executive jointly funded a project named “Higher-order Wave Load Effects on Large Volume Structures” (Ringing Joint Industry Project, 1993), which was focused on a series of field observations, experimental models, and numerical simulation research on TLP, and produced some very valuable results. Petrauskas and Liu (1987) carried out two model tests on springing, one measuring springing forces on a vertical cylinder and the other measuring the response of a TLP. Kim et al. (1997) and Zou et al. (1998) also experimented with a model of the ISSC TLP to measure the force and then obtained the response of the platform solving the equations of motion. Zhou and Wu (2015) and Zhou et al. (2017) studied the springing induced by triple frequency wave force for a TLP and barge, respectively. In the simulations, while there is work based on semi-empirical equations by Wang and Kim (2001), most research on higher-order loads is based on the perturbation theory up to the third order. Typical examples include that by Faltinsen et al. (1995) for a slender cylinder in long waves and that by Malenica and Molin (1995) for a cylinder in finite water depth. Teng and Kato (2002) also calculated the third-order wave load at the triple wave frequency on fixed axisymmetric bodies by monochromatic waves. However, one may note that the perturbation theory is valid only for moderate waves.

These studies provided good references for the springing related to the floating offshore wind turbine systems (FOWTs). However, they may not be directly applied to them, where the interaction between the turbine and the platform, or between aerodynamics and hydrodynamics, plays an important role, while such interaction does not exist for the platforms used for the oil and gas exploration. Nevertheless, no publication has been found in literature that studied the springing of TLPWT.

As springing is caused mainly by nonlinearity, it is reasonable to think that a fully nonlinear theory is required to study this phenomenon. The fully nonlinear theories include general flow theory (GFT) and fully nonlinear potential theory (FNPT). The GFT is based on the Navier-Stokes (NS) and continuity equation, which

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KEY WORDS: Fully nonlinear potential theory, springing, tension-leg-platform wind turbine, third-harmonic force.