Springing Response of a Tension-leg-platform Wind Turbine Excited by Third-harmonic Force in Nonlinear Regular Waves

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ABSTRACT

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

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

INTRODUCTION

The offshore wind farm development began in shallow water areas by placing wind turbines on fixed (seabed mounted) structures. However, most of the global offshore wind resource is available in the location, where water is much deeper and deploying wind turbines on fixed support structures becomes economically infeasible. Therefore, it is strongly desired to develop a cost-effective floating platform to support a wind turbine that can compete with other energy sources.

The prime requisite for floating wind turbine systems is their ability to withstand environmental forces, albeit with some degrees of oscillations. If the floating platform allows the system to tilt appreciably, the behavior of a wind turbine would be affected even to such an extent that possible operating limitations and/or energy output reductions would have to be considered for estimating LCOE. One of the best promising concepts for a floating wind turbine is deemed to be a mooring line stabilized tension-leg-platform (TLP) that experiences minimal tilting movement.

Moreover, it is lightweight and has fewer mooring footprints as compared to its counterpart. Favorable indications for the adoption of the TLP system have also been given by technical and economic results produced by a separate study carried out by Musial et al. (2003) and Italian Electrical System (Casale, et al., 2010). TLPs are generally designed to keep their natural frequencies in heave, pitch, and roll degrees of freedom, several times above the dominant wave frequencies, whereas in the surge, sway, and yaw degrees of freedom below them. Though their natural frequencies are far away from the dominant wave frequencies, the non-linear effect can give rise to force components near their natural frequencies. Even if these force components are small, their effect on the dynamic response can be significant.

As per International-Electrotechnical-Commission (IEC) standards, floating wind turbines are designed to survive 50-years of extreme environmental conditions during their 20-years of service life. For a TLPWT, extreme wave loads can induce high-frequency resonance and transient responses, e.g., springing and ringing, which may greatly amplify its global responses. A springing, which is usually referred to the resonance oscillations, is highly relevant to the fatigue analysis of the structure. As TLPWT’s are designed to avoid resonance by linear force at the dominant frequency of the wave spectrum, they are likely to get excited by the nonlinear force at harmonic components, where, is two, three... It is then evident that springing is principally due to the higher harmonic components of the nonlinear wave force. Thus, in the present work, we shall consider the resonant 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. Though the resonance responses of a structure typically occur when its natural frequency is about three to five times the incoming wave frequency, it is most likely to get excited by the third-order force at the triple wave frequency. Therefore, our focus in this paper will be on the third-order effects.

In the past, extensive efforts were made to improve the understanding of the springing related to the high-frequency response and to develop numerical tools to predict it. The Norwegian Petroleum Directorate and the UK Health and Safety Executive jointly funded a project named...