論 文 の 内 容 の 要 旨

論文題目

Prediction of Tower Loading of Floating Offshore Wind Turbine Systems in the Extreme Wind and Wave Conditions

（浮体式洋上風車のタワーに作用する暴風波浪時の荷重の評価）

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The urgent concern about global warming from the emission of greenhouse gases has provided a strong impetus for engineers and scientists worldwide to research alternative renewable and clean energy. Wind power is one of the fastest growing renewable energy technologies. Onshore wind farms are, however, unsightly and they swallow up valuable land for agriculture and urban development. Already some countries, are considering constructing huge wind farms offshore to take advantage of the generally steadier and stronger winds found in the sea. Moreover, the wind turbines can be larger than those on land because they can be transported to the site by sea. In Japan, the offshore consist of a vast wind resource in deep water where use of conventional bottom-mounted wind turbines is not possible, and floating wind turbines are the most attractive. Thus, it is necessary to consider the effect of floater motion on the tower loading to check the serviceability of the wind turbines which are designed for the bottom-mounted systems.

In the current study, the tower loading is taken as the combination of wave-induced load and wind-induced load. Since their coupling is negligibly small, the analytical formulae are proposed for each kind of load independently. Sway-rocking (SR) model is used as the equivalent calculating model, and the reason why the fixed-foundation model can not be used is presented. For wave-induced load, the influence of each floater motion is investigated separately and their combination is carried out. The resonance of tower vibration will increase the tower loading. For wind-induced load, both along-wind direction and across-wind direction are investigated and their combination is performed as well. Finally, in the combination of wave-induced load and wind-induced load, the load reduction factor changes with wave period, different from the constant value given in IEC for bottom-mounted system. All the results have been verified by the dynamic response analysis of a fully coupled finite element model.

Chapter 1 is a review of current situation of offshore wind energy around the world and in Japan. It explains why it is essential to use floating wind turbine systems in Japan. The outline of this dissertation is also presented.

In Chapter 2, a literature survey of research and development on floating wind turbines is presented. An overview of the research work that has been undertaken pertaining to floating wind turbine technology thus far is carried out, and based on its conclusions and limitations, objectives of this research are presented.

In Chapter 3, two kinds of floating systems: tension leg mooring system and catenary mooring system are considered. Surge is the dominant floater motion caused by wave for tension leg system, while for catenary system pitch motion is significant as well as surge motion. Takahashi used the fixed-foundation model with acceleration acting on tower base to consider the influence of floater motion on the fatigue load. However, this fixed-foundation model is not verified, and in most cases it can't be used. In this research SR model is used as the equivalent model to calculate the tower loading. The stiffness, damping and equivalent wave force of each mode are recognized. A theoretical comparison between SR model and fixed-foundation model is performed with modal analysis and thus give a clear explanation why the latter model can not be used.

Chapter 4 uses SR model to predict the wave-induced load under regular and irregular wave respectively. Since the aerodynamic effect due to floater motion is negligibly small, which means the coupling between wave-induced load and wind-induced load can be ignored, the wave-induced load is investigated independently. The effect of sway (surge) motion as well as rocking (pitch) motion is investigated separately by locking the other mode. The combination of sway motion effect and rocking motion effect is calculated with complete quadratic combination (CQC) rule, and their correlation only depends on the damping and natural frequency of the system. For irregular wave, the maximum wave load can be calculated with the product of standard deviation and peak factor. It is noticed that the resonance of tower vibration causes the non-Gaussian feature and increases the tower loading. This effect will decrease with wave period, since the external exciting effect becomes weaker.

Chapter 5 gives details of the prediction of wind-induced load. Equivalent static method is adopted to estimate the maximum wind load on wind turbine towers. In both along-wind direction and across-wind direction, the analytical formulae are proposed for mean wind load and gust loading factor which contains standard deviation and peak factor of fluctuating wind load. The critical parameters in the standard deviation such as mode correction factor, aerodynamic damping ratio and size reduction factor are investigated to identify the dominant influence factors and their characteristics. A non-Gaussian peak factor which can be reduced to the standard Gaussian form for a Gaussian process is proposed. For floating wind turbine, SR model should be employed for the wind-induced load prediction, since the low natural frequency increases the resonant standard deviation, while the large damping causes significant reduction. Considering the wind response correlation of along-wind direction and across-wind direction, a loads combination formula is proposed to calculate the final design wind load on towers.

Chapter 6 presents the combination of wave-induced load and wind-induced load. Perfect correlation causes overestimation. In this study, the wind induced load and the wave induced load are assumed to be perfectly uncorrelated and the load reduction factor is introduced. It was found that the estimated reduction factor is less than the value specified in international design standard for offshore wind turbine, IEC61400-3.

Chapter 7 summarizes the conclusions of this study. An equivalent SR model is proposed to calculate the tower loading due to wave and wind. The evaluation formulae for wave-induced load are proposed, considering the influence of each floater motion separately and their combination with CQC rule. The resonance of tower vibration causes the non-Gaussian feature and increases the tower loading. The evaluation formulae for wind-induced load are proposed as well and the characteristics of critical parameters are identified. Finally, the load reduction factor is proposed in the combination of wave-induced load and wind-induced load.