A fundamental investigation of the floating overhead power transmission system

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論 文 名　：A fundamental investigation of the floating overhead power transmission system

（浮体式洋上架空送電システムに関する基礎検討）

区　　分 ：甲

論　文　内　容　の　要　旨

Thesis Summary

The increasing demand for energy consumption urges seeking safe, clean and renewable energies. In recent years, many countries have set a series of national-wide policies on exploiting ocean renewable energies to fulfil their goal of decarbonization. Since Japan possesses an immense exclusive economic zone, fully developing its own energy potential is the key to ensuring energy security.

The present thesis concentrates on offshore power transmission, an essential research topic relating to the productivity of ocean energy development. In past engineering practices, submarine cables were the only feasible solution. However, its maintenance cost, transmission loss and sensitivity to the seabed environment restrict its applications. According to the deep-water environment in the surrounding seas of Japan, the present work proposes a floating overhead power transmission system (FOPTS) that uses TLP to support transmission conductors learning from the experience of floating offshore wind turbines (FOWTs). In addition to the numerical modelling, water tank experiments and wind tunnel tests are also carried out to verify the reliability of the system, so as to provide guidance and inspiration for subsequent research.

Chapter 2 focuses on the process and development environment of numerical modelling. First, dynamic modelling of the TLP system is carried out based on classical mechanics, and the overhead conductor are modelled using the lumped-parameter method. Meanwhile, the offshore wind and waves are modelled using the potential flow theory and the wake oscillator model. Wind-wave misalignment, turbulence effect of winds, and other factors were added to the model to consider the actual offshore environment. Using MATLAB SIMSCAPE®, each mechanical module is designed separately and can be freely combined to perform efficient FOPTS numerical simulations.

Chapter 3 introduces the water tank experiment for verifying the hydrodynamic module. A TLP model is created using 3D printing and equipped with a pulley-wire system to study the wire response. The response of the tower-wire system under regular waves reveals that the sheave mechanic can effectively suppress the motion of the wire without changing the dynamic performance of the TLP itself. At the same time, the experimental results are compared with the numerical simulation, and good consistency is obtained to prove the reliability of the numerical model.

Chapter 4 introduces the parametric design workflow for FOPTS. Based on the conclusion of Chapter 3, the parameters

of TLP and overhead conductor are separately designed in the frequency domain. Based on the research of National Renewable Energy Laboratory (NREL) and Zhao et al. (2012), a three-legged TLP with better hydrodynamic performance is used to ensure the stability of overhead conductor. The newly designed FOPTS parameters are fully listed at the end of the chapter.

Chapter 5 introduces the wind tunnel test for verifying the aerodynamic module of overhead conductor. The TLP motion in waves is simulated by a stepper motor, and the tension and motion responses of the conductor are studied under different wind and wave conditions. The influence of Everyday Strength (EDS) and subharmonic resonance on the dynamic performance of overhead conductor was observed through experiments. The experimental results are in good agreement with the simulation, proving the reliability of the lumped-parameter method and wake oscillator model in numerical modelling.

Chapter 6 conducts a series of numerical simulations. Based on the environmental data from the Sea of Japan, the response of FOPTS equipped with different types of ACSR conductors is simulated. The numerical study focuses on the safety assessment of the conductor, mooring line and ship navigation. It is found that different conductors respond differently, and an overweight conductor is more sensitive to wind and wave misalignment under extreme wind and wave conditions. Although an overweight conductor has higher power transmission efficiency, they should be used carefully in consideration of stress safety. The effect of conductor motion on ship navigation is also studied, and safety clearance for daily navigation is obtained. Regarding mooring lines, the change of wave direction has little effect on the tendon force of the three-legged TLP, while the extreme wind condition affects the lower limit of tendon tension, which is the main factor affecting mooring safety. The influence of the second-order wave force on the calculation accuracy of the conductor response is studied. It is found that when the EDS is small, the influence of the second-order force on the conductor response is more apparent, and the influence of the EDS is less than 3% when the value of the EDS is selected according to the design conditions, which can be ignored to improve the computational efficiency.

Chapter 7 summarizes the main conclusions. When the sheave mechanic was introduced, it was proved effective in separating each part of FOPTS for frequency design. Wind-wave misalignment has a clear impact on the performance of overhead conductors, which should be considered in designing. For the design of the overhead conductor, the setting of Everyday strength (EDS) is the most critical, and subharmonic resonance is an essential factor to the safety of power conductor under regular sea conditions. Through experimental verification, the numerical model proposed in this study has been proven reliable. Improvements and prospects for future research are also given at the end of this chapter.