Dynamic Analysis of Offshore Wind Power Platform Based on Nonlinear Wave Model

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Abstract: In terms of basic theory on numerical method of nonlinear wave model, applicable range is selected in this paper to analyze both advantages and disadvantages of various numerical methods from the aspects of calculation efficiency and calculation accuracy and offer comprehensive suggestions, which supports hydrodynamic design of combined power generation system.

1 Introduction

Compared with currently more mature offshore wind energy, conversion and utilization technology of wave energy and tidal energy is in initial development. However, driven by awareness of energy conservation and emission reduction since the 21st century, it has entered a period of rapid development. Despite different degrees of development, marine environment offshore wind and wave energy as well as tidal current energy facing is similar.

Development of marine renewable energy needs to effectively use various natural resources and reduce installation costs, which makes comprehensive development of multiple energy sources imperative trend. Moreover, if new devices can be installed on existing support structures and transmissions, cost will be effectively reduced. In terms of combining with offshore wind energy, wave energy has certain advantages compared with tidal energy. For example, locations with abundant wind resources usually exist abundant wave resources. Therefore, benefits combined wave energy devices with offshore wind turbine platforms are as follows [1-2].

(1) Since the two share ocean space, energy output per unit of sea area can be increased.

(2)As mooring system, power infrastructure equipment and other components are shared, it can improve overall economic efficiency.

(3)Offshore wind power is fluctuating with strong irregularities and poor stability. However, wave energy is more stable than wind energy.

Therefore, compared with separate wind power system, combined power generation system of the two can reduce the number of non-operation hours. In addition, since wave energy device absorbs wave energy near offshore wind turbine platform, and local wave field is changed, wind turbine can be effectively protected from strong waves when layout is reasonable. Combined structure of wave energy device and offshore wind turbine platform is shown in Figure 1. Moreover, there are many aspects related to multi-floating body hydrodynamic problems. For example, in numerical simulation, it can be mainly divided into linear method where frequency domain and time domain methods exist, potential flow nonlinear method and viscous method. Besides it, experimental methods are also varied [3].

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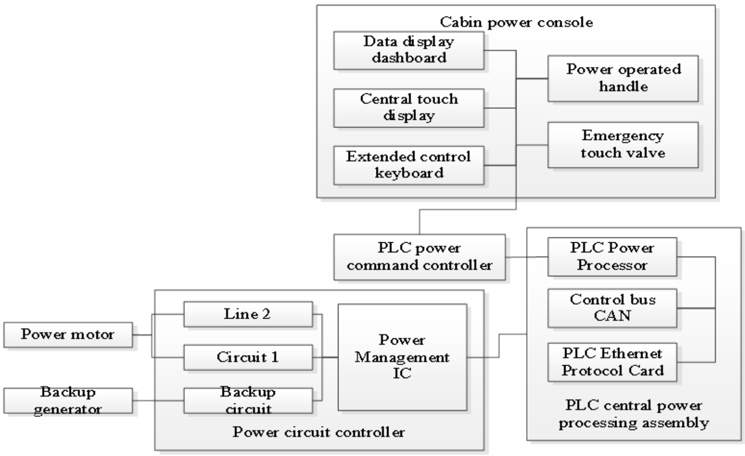

Figure 1 Main structure of power comprehensive acquisition platform

2 Non-linear Method of Potential Flow

Since boundary conditions of potential non-linear method are satisfied on instantaneous water and object surface, free water and object surface grid must be updated in real time every time. What's more, compared with above-mentioned linear method, calculation amount and memory requirements are greatly increased. Rigid body equation of motion for single floating body is as follows.

$$M\ddot{X}(t)+B\ddot{X}(t)+KX(t)=F_L(t)+F_G \tag{1}$$

Among them, M is mass matrix of floating body, B and K respectively indicate damping matrix and stiffness matrix, and X refers to floating body displacement. Besides it, F represents excited vibration force of floating body, $F_L(t)$ is fluid force, and F_G is gravity of object. Additionally, restoring force has been already included in $F_L(t)$.

At present, there is less literature on motion response of multi-floating bodies based on potential flow nonlinear theory. Therefore, quasi-static finite element method is used to simulate coupling motion of monochromatic and bichromate waves with Spar platform and monochromatic waves with one and two Wigley ships[4-5]. Besides it, non-linear potential flow method combined with viscous modified damping force method is used to simulate inflow and outflow of STC device under survival sea conditions, which is in good agreement with experimental results. What's more, most applications of three-dimensional completely nonlinear numerical models are limited to single floating bodies, and interaction of regular waves with floating uniform cylinders and variable-section cylinders has been simulated according to high-order boundary element methods combined with partitioning techniques. In addition, based on higher-order boundary element method and utilization of in-scattered wave separation technology, three-dimensional numerical model of completely non-linear interaction between waves and single floating bodies in open waters is established as well. Meanwhile, high frequency resonance problem of tension leg platform in round table is simulated. When potential flow nonlinear method is used to calculate multi-floating body motion problem, as the number of grids increases, requirements for computing resources also increase dramatically. Therefore, method proposed in this paper is mostly used to calculate response and load of offshore structures under extreme sea conditions such as strong winds and waves. As for wind and wave combined power generation systems, no potential current nonlinear method has been used for simulation [6-7].

3 Experiments and Optimized Control

Concept of wind-wave combined power generation system is proposed, and a scale test of scale ratio is carried out in towing tank of MARINTEC, in which fans are designed with principle of similar axial thrust. Moreover, similar to offshore wind turbine model experiment, wind turbine model in wind-wave combined power generation system needs to be redesigned based on similar Reynolds number, or other new experimental techniques are used to solve mismatch between Fourier number and Reynolds number. What's more, optimization and control of combined power generation system plays decisive role in improving hydrodynamic energy conversion efficiency of floating body in wave energy device, especially in irregularly changing wind and wave environment. Meanwhile, if floating body can effectively absorb and intercept wave energy, hydrodynamic load of surrounding offshore wind turbines will be greatly reduced. In addition, basic working principle of floating body control is as follows. Wave power output device in power generation system applies control force to floating body coupled to it while converting wave energy into electrical energy to coordinate dynamic response of floating body. Meanwhile, in order to make floating body more effectively absorb energy carried in incident wave, floating body should generate specific ideal movement under coordination of control force to intercept propagation of incident wave [8].

Based on derivation of linear potential flow theory, specific ideal movement of floating body needs to meet two basic conditions to maximize energy absorption.

(1) Speed of floating body must be in the same oscillating phase as pressure exerted by incident wave on floating body, which means that floating body forms resonance with incident wave.

(2) Downstream radiation wave generated by floating body oscillation is canceled by incident wave.

Under real-time changing wind and wave environment, if optimal energy absorption control theory mentioned above can be realized in actual control system, following scientific research challenges will be faced.

(1) If floating body needs to resonate with incident wave whose frequency changes in real time, wave energy power output device will have to implement "reactive control" so as to have the functions both generator and driver own, which will greatly increase difficulty and cost of device.

(2) Due to random variation of irregular wave, force applied to floating body by incident wave needs to be predicted, and accuracy of prediction result has direct impact on control effect.

(3) This control theory is based on linear hydrodynamic model, which is not applicable to nonlinear models under high sea conditions.

(4) Floating body needs to vibrate in at least two degrees of freedom, such as swaying and pitching so that incident wave energy can be more effectively absorbed.

In case of multiple floating bodies that are commonly used in wind-wave combined power generation system arrays, degrees of freedom required for control are multiplied and coupled with each other, which will greatly increase complexity and cost of control system.

Considering many technical difficulties mentioned above, the research direction with more application potential at this stage is to achieve more simple and effective sub-optimal control. Taking the control method as example, "passive control" system which can be divided into "phase control" and "passive load" has received more extensive attention from performance scholars than "reactive control". Moreover, "phase control" is designed to force floating body system to resonate with incident wave, which is usually realized by mechanical braking system, and its energy conversion efficiency is close to that of "reactive control" under ideal conditions. However, nonlinear characteristics and control robustness of "phase control" require more in-depth research and certification to achieve higher application value. On the other hand, "passive load" only considers real-time matching of power generation device and hydrodynamic impedance, which is simple, reliable, and easy to implement in mechanism. Besides it, power generation efficiency and controllability of "passive load" are much lower than that of "reactive control" and "phase control", which greatly limits its application value.

4 Comparative Analysis on Hydrodynamic Numerical Methods

Through comparative analysis of various numerical methods, it can be seen that for different problems, different numerical calculation methods should be selected in combination with calculation efficiency and accuracy, as shown in Table 1.

Table 1 Comparison of different hydrodynamic numerical methods

Numerical methods	Time unit of measurement	Calculation efficiency	Calculation accuracy
Linear frequency−domain	second	****	*
Linear time−domain	minute	***	**
Nonlinear potential	day	**	***
Viscous method	week	*	****

Table 1 shows comparison among different numerical calculation methods in terms of calculation efficiency and accuracy. The higher level is, namely more asterisks there are, the higher calculation efficiency and accuracy will be. What's more, in terms of calculation time, linear frequency domain method has the highest calculation efficiency, which only applies to steady-state problems. Then, linear time domain method is suitable for transient problems. If the same steady state problem is calculated, calculation accuracy will be the same as frequency domain method. If transient problem is calculated, calculation accuracy will be higher than that of frequency domain method. Besides it, since potential flow non-linear method requires matrix equation to be re-established and solved on instantaneous surface at each moment, calculation efficiency is much lower than that of the previous two. However, considering non-linearity of object and free water surface, calculation accuracy is higher when problem of strong non-linearity, namely extreme sea conditions, is solved. Additionally, as viscous method considers effects of both non-linearity and viscosity, calculation efficiency is the lowest, but calculation accuracy is the highest.

Different numerical models need to be selected according to different problems. If considering optimization design of wind-wave joint system under normal operating conditions, linear frequency domain method can be used. Moreover, if optimization design problem under non-steady state is considered, such as unsteady wind and transient waves, linear time-domain method will be needed. Besides it, for linear frequency and time domain methods, when the number of floating bodies is large, acceleration algorithm needs to be considered. Compared with characteristic scale or wavelength of object, when wave amplitude and motion scale loudness of object are not small, such as strong winds and waves, linear theory will be no longer applicable, where potential current nonlinear methods will be applied for calculation.

Potential flow theory ignores fluid viscosity. When fluid viscosity is more important, such as solving small-scale objects as oscillating float-type wave energy devices, viscosity method needs to be used for calculation. Although viscous method has high calculation accuracy, it has low calculation efficiency, especially for problem of a large number of grids such as wind-wave joint system. Viscosity is only used when directly calculating cases where viscosity of fluid is particularly important in extreme sea conditions. Therefore, comprehensively considering calculation efficiency and accuracy, it is feasible solution to study potential flow theory with viscosity correction which needs to be obtained through viscosity method or experimental results.

5 Summary and Discussion

Optimized control technology is particularly critical to improving hydrodynamic performance of combined power generation system. However, regardless of requirements for control hardware or control algorithms, there are many technical difficulties in optimal energy absorption theory, and optimized control methods have attracted wider attention from industry scholars. In addition, control is an extremely complex research topic, which will not be described in detail in this article so that readers can understand supporting role of control methods in hydro-power design optimization in combined power generation systems.

Physical model experiments are important means of verifying accuracy of numerical models and reliability of device. However, since wind wave combined power generation system involves both hydrodynamic force of structure and aerodynamic force of fan, physical model experiment faces many challenges. Additionally, selection on similarity ratio of model experiment has greater impact on the results, and offshore platform and wave energy device select model scale ratio based on similarity of Fourier numbers. Besides it, fan needs to choose its size according to the similarity of Reynolds number, which is difficult to meet in experiment. What's more, due to the influence that Reynolds number mismatch under scale of Reynolds number, model test cannot reflect characteristics of combined power generation system in real sea conditions. At present, experimental technology in this area is still in exploration stage, where new experimental methods are required to solve problems mentioned above.

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