Appl. Math. Mech. -Engl. Ed., **37**(Suppl.), S1–S10 (2016)

Applied Mathematics and Mechanics (English Edition)

Offshore floating wind turbine and its dynamic problems*

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Abstract Green energy sources and ocean wind power are plentiful in deep sea. More and more offshore wind power plants are constructed in the deep water over hundred meters below the surface. While offshore floating wind turbine system is working, wind turbine, floating foundation, and mooring system affect each other with wind, waves, and currents acting on them. Various offshore floating wind turbine systems and the encountered environmental loads are briefly reviewed and discussed. It is difficult and crucial to comprehensively analyze the aerodynamic-hydrodynamic-service system-structure under the coupling effect of offshore floating wind turbine system. The environmental flow field, structure scale, and rational applications of theories and approaches should be well considered in advance.

Key words ocean wind power, offshore floating wind turbine, coupling, dynamics

Chinese Library Classification O352
2010 Mathematics Subject Classification 85A30

1 Introduction

Wind energy is one of the most important renewable and clean energy resources. The generation of power from wind can be achieved by wind turbines, which convert wind energy to electrical energy. After decades of development, there have been remarkable progresses in wind energy technology of the utilization of offshore and onshore wind. Offshore wind energy has a special virtue for stable wind and wide wind farm on sea. It can save land resource comparing with onshore wind farm and reduce wind electricity cost[1].

There is a special difficulty for offshore wind energy technology. The environment of offshore wind turbines constructed is very complex. The influence of the main weather and hydrology factors of wind, waves, and currents acting on wind energy facility should be paid attention to. The influence of ice should be noticed in ice area. For an offshore floating wind turbine system, the motion and mooring system should be considered. It may bring maintenance problems of long period. Abundant offshore wind energy resource exists in the water over 30 m below the surface. The economy efficiency of offshore fixed wind turbine system constructed in these areas declines. The offshore floating wind turbine systems have developed rapidly. In terms of installed power, the main projects are the Lynn and Inner Dowsing (194 MW), the Kentish Flats project (90 MW), and the Burbo Banks project (90 MW) in the U. K., the Q7 project (120 MW) in the Netherlands, and the Nysted offshore Windfarm (165 MW) and the Horns Rev project

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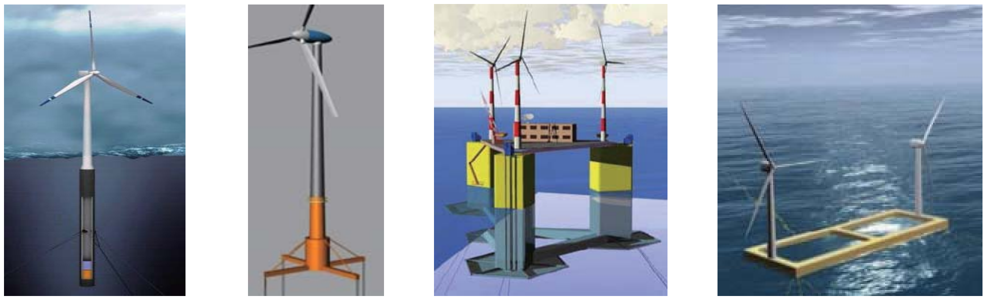
(160 MW) in Denmark. The wind energy farm is constructed in more deeper water, and some typical offshore floating wind turbine systems are proposed, such as the spar type floating wind turbine of 5 MW designed by the National Renewable Energy Laboratory[2] and the floating wind turbine of 2.3 MW installed in the water of depth 220 m in the North sea.

The offshore floating wind turbine is a new kind of ocean engineering device, comparing with the traditional ocean engineering device. Its whole structure is quite higher and loaded with more wind and waves, and the corresponding nonlinear dynamic responses become more complex. This paper presents various floater concepts outlined so far and gives the main development of research on the dynamic problems related to offshore floating wind turbine systems. Recommendations for future work are also suggested.

2 Offshore floating wind turbines

There are two types of platforms for offshore wind turbines. One is for offshore fixed wind turbine installed in shallow water, and the other is for offshore floating wind turbine usually constructed in the depth of over 60 m underwater. Compared with the land wind turbine system, the complex platform directly influences the working stability and reliability of wind turbine. The offshore floating wind turbine system consists of wind turbine, floating platform, and mooring system. In 1994, Garrad Hassan, a UK company, firstly started to study on the floating foundation in detail[3]. A single turbine installed on the spar type platform with a catenary mooring system was evaluated, and some related foundations of wind turbine and mooring system were discussed. In the following, some companies in Italy, US, and Norway carried out the similar research. Drawing from the design classifications of floating foundations for the offshore oil and gas industry, floating wind turbines can also be categorized into four main types: spar-buoy type, tension-leg platform (TLP) type, semi-submersible type (column stabilized), and pontoon type (Barge type). As shown in Fig. 1(a), the floating foundation (consisting of a steel and/or concrete cylinder filled with a ballast of water and gravels to keep the centre of gravity well below the centre of buoyancy) ensures the wind turbine floats in the sea and stays upright since it creates a large righting moment arm and high inertial resistance to pitch and roll motions. It should be remarked that the spar type foundation is difficult to be capsized. The draft of the floating foundation is usually larger than or at least equal to the hub height above the mean sea level for stability and to minimize the heave motion. The spar floating wind turbine is usually kept in position by a taut or a catenary spread mooring system using anchor-chains, steel cables, and/or synthetic fibre ropes. Alternatively, it may be moored by a single vertical tendon held at the base by a swivel connection that allows the wind turbine to revolve as the direction of wind changes. The TLP type comprises a floating platform structure to carry the wind turbine, as shown in Fig. 1(b). The pretension tethers provide the righting stability. This type of floating wind turbine has relatively less dynamic response to waves when compared with the spar-buoy type, the semi-submersible type, or the pontoon type, but is subject to a phenomenon known as pull down, which is an increase in draft as the platform is offset from its equilibrium position. The semi-submersible type comprises a few large column tubes connected to each other by tubular members. A wind turbine may sit on one of the column tubes, or there could be wind turbines sitting in all the columns. Alternatively, the wind turbine may be positioned at the geometric centre of the column tubes and supported by lateral bracing members. The column tubes provide the ballast, and they are partially filled with water. In the afloat condition, the water-plane area of the columns primarily provides floatation stability, hence the term column stabilized. The pontoon type has a very large pontoon structure to carry a group of wind turbines. The large pontoon structure achieves stability via distributed buoyancy and by taking advantage of the weighted water plane area for righting moment. The pontoon type may be moored by conventional catenary anchor chains. However, the setback of the pontoon type wind turbine is that it is susceptible to the roll and pitch motions in waves experienced by ocean-going shipshaped vessels and may only be sited in calm seas, e.g., a harbor, sheltered cove, and lagoon[4–6].



(a) Spar type foundation (b) TLP foundation (c) Semi-submersible foundation (d) Pontoon type foundation

Fig. 1 Four main types of floating foundation of offshore wind turbine

It should be remarked that there are clearly hybrid types of floating wind turbines, for example, a combination of spar floater and tension leg mooring system. Also, there is an interesting concept of a sailing type floating wind turbine that was studied at the National Institute for Environmental Studies, Japan (2007). The floating wind power plant has no mooring system but navigates with sails and azimuth thrusters. The self-sailing and self-propelled mobility allows the wind farm to move to a location that maximizes the generation of wind power as well as to weather route from storms. The lower and upper hulls of the slender are lightweight composites to minimize construction costs and enhance the propulsion.

3 Environmental and structural loads on offshore floating wind turbine

Comparing with onshore wind turbine, offshore floating wind turbine would experience not only wind loads but also wave and current loads, and the loads differ from those on the offshore oil platforms. It is difficult to analyze the dynamic response of offshore floating wind turbine system under the combination loads of wind, wave, and current. The coupling problem of aerodynamics, hydrodynamics, and structure dynamics becomes a very hot research topic, because it is of great importance to accurately describe the specific sea state and evaluate relevant environmental loads on offshore floating wind turbine system.

3.1 Wind loads

Wind loads mainly act on the parts of wind turbine system above water, such as tower, part of floating foundation, and rotor blade. Assume that the wind direction is parallel to the water level without the vertical wind component. The instant wind speed $u(z, \mathrm{t})$ can be regarded as a steady component with the time varying fluctuation components, which are the mean wind speed and the pulse wind speed.

3.1.1 Mean and pulse wind speeds

The mean wind speed varies with the height due to the influence of the sea surface roughness. The rule of the mean wind speed varying with the height can be represented by both exponential and logarithmic rules. The exponential rule is expressed as

$$u(z) = u_{\mathrm{r}}(z/z_{\mathrm{r}})^{\alpha}, \tag{1}$$

where z is the height above the water plane, $u(z)$ is the mean wind speed at the height z, u_{r} represents the speed at the reference height z_{r}, which is normally 10 m, and α is the height coefficient increasing with the water surface roughness.

The logarithmic rule can be written as

$$u(z) = u_{\mathrm{r}}\frac{\ln z - \ln z_0}{\ln z_{\mathrm{r}} - \ln z_0}, \tag{2}$$

where z_0 is the corresponding height at which the mean wind speed is equivalent to zero.

It is well known that the fluctuation of time varying wind speed is assumed to be a Gaussian stochastic process with the mean of zero. Therefore, the pulse wind speed can be described by some wind gust spectra, usually expressed in the mean wind direction or the direction perpendicular to the mean wind direction. In engineering, there are many spectra in the mean direction, the Harris, the Davenport, the Wills, e.g., the ISO 19901-1 (NPD), and the API wind gust spectrum[7–8].

3.1.2 Computations of wind loads

Wind loads mainly act on tower and rotor blade. Practically, the momentum-blade element method is widely used to evaluate aerodynamic loads and assess performance of wind turbine. This method incorporates both theories of momentum conservation and blade-element. The former predicts wind loads based on the macro-model, and the later gives the computation of wind loads from detailed lifting and drag forces. By further integrating the turbulence model and corrections of blade angle attack, wind loads on wind turbine can be obtained. Ye et al.[9] made simulation for wind turbine blade combining the lift line theory and the panel method. The results of the output power of blade are in good agreement with the measured data. With development of computational fluid dynamics (CFD) and computer, CFD incorporated with the turbulence model and moving mesh technique is applied to solve wind loads on wind turbine. However, the CFD is quite time consuming.

Currently, to obtain the globe response of offshore floating foundation, the simplified model is usually used to determine blade thrust. For example, Knauer et al.[10] adopted the following equation:

$$F_{\mathrm{T}} = \frac{1}{2}\rho_{\mathrm{a}} A U_{\mathrm{r}}^2 C_{\mathrm{T}}(U), \tag{3}$$

where ρ_{a} is the air density, A represents the total area of blade sweeping over, C_{T} is the thrust coefficient, and U_{r} denotes the relative wind speed. If C_{T} is replaced by the drag coefficient, the equation above can be used to calculate wind loads on tower.

3.2 Wave and current loads on offshore floating foundation

Hydrodynamic interactions between waves (current) and different types of floating foundation show different phenomena. In the view of scale of floating structure under water, comparing with the wave length, it can be categorized into slender body and floating structure with a large scale. The wave and current loads on structure resulted from different mechanisms. For example, wave induced loads on cylinder in oscillatory flow are determined by the Reynolds number and the Keulengan-Carpenter number $N_{\mathrm{KC}} = U_{\mathrm{M}}T/D$, where U_{M} is the maximum speed, T is the oscillatory period, and D is the cylinder diameter. Generally, when $N_{\mathrm{KC}} < 10$, the inertial force becomes more important as N_{KC} decreases. When $N_{\mathrm{KC}} > 15$, the viscous force becomes important with the increase of N_{KC}. When $N_{\mathrm{KC}} > 5$, the lift force becomes significant. For teh structure with slender bodies under water, the viscous force cannot be neglected, while for the semi-submerged floating foundation, the wave force is dominant because N_{KC} approximates to 1. Therefore, different methods should be adopted to evaluate hydrodynamic loads on floating structures according to their scales.

3.2.1 Hydrodynamic loads on slender body

With respect to the mooring cable and pipe with small diameter, Morison's equation is used to compute the hydrodynamic force. Wave and current forces on the slender body can be computed by

$$F(t) = \frac{\rho\pi D^2}{4}\frac{\mathrm{d}U(t)}{\mathrm{d}t}C_{\mathrm{M}} + \frac{\rho D}{2}C_{\mathrm{D}}(z)U(t)|U(t)|, \tag{4}$$

where $F(t)$ is the horizontal force acting on z, D is the diameter, ρ is the fluid density, C_{M} represents the mass force coefficient, C_{D} denotes the drag coefficient, and $U(t)$ is the fluid velocity in the horizontal direction.

If the dominated load on floating structure is mainly on slender bodies, high order wave loads should be considered. The 5th-order Stokes wave theory is usually recommended to compute wave loads by standards of each classification society. Velocity potential of 5th-order Stokes waves can be derived by the perturbation theory (refer to chapter 5 in Ref. [11]). Wave loads in irregular waves can be achieved by superposition of components of wave loads in regular waves with different frequencies which are decomposed from wave spectrum.

With regard to slender body in sea current, vortex-induced vibration should be considered. It is well-known that the vortex separation frequency of flow around cylinder is $f_{\mathrm{s}} = Sr\,U/D$, where U is the current speed, D is the cylinder diameter, and Sr is the Strouhal number, a similarity parameter related to Re and the cross section shape. When the frequency of vortex separation approximates to the natural frequency of structure, severe transverse vibration occurs. Structural vibration could enhance vortex, arise drag force, and force vortex separation frequency approximate to the natural frequency of structure. Vortex-induced motion has negative influence on the single spar type wind turbine. Thus, the effect of current should be considered in design to avoid resonance.

3.2.2 Wave load on floating foundations with large scale

The computational method of wave load on the large-scale foundation of floating wind turbine system is the same as the method for offshore platform. Presently, a three-dimensional potential theory method is generally adopted with supplement of revised viscous damping. The linear wave load on the offshore wind turbine floating foundation is primarily regarded as the sum of the incident wave force, the diffraction wave force, and the radiation wave force due to motions of foundation.

Assume that the fluid is inviscid and incompressible and the flow is irrotational. The flow velocity potential satisfies the Laplace equation, the flow velocity on wetted surface of floating body conforms the impermeable condition, there are nonlinear kinematic and dynamic conditions on the free surface, and the radiation condition should be satisfied at infinity as well. The velocity potential ϕ can be decomposed as $\phi = \phi_{\mathrm{I}} + \phi_{\mathrm{R}} + \phi_{\mathrm{D}}$, where ϕ_{I} denotes incident potential, ϕ_{R} represents the radiation potential, and ϕ_{D} is the diffraction potential. Using the potential theory to solve the radiation and diffraction problems of floating foundation in waves, it is equivalent to solving the initial boundary value problem with respect to the Laplace equation of the velocity potential ϕ. The problem of the radiation potential ϕ is defined by

$$\begin{cases} [L]: \dfrac{\partial^2\phi}{\partial x^2} + \dfrac{\partial^2\phi}{\partial y^2} + \dfrac{\partial^2\phi}{\partial z^2} = 0, \\ [F]: \dfrac{\partial^2\phi}{\partial t^2} + g\dfrac{\partial\phi}{\partial z} = 0, \\ [S]: \dfrac{\partial\phi}{\partial n} = \dot{\xi}_k(t)n_k, \\ [B]: \phi, \quad \dfrac{\partial\phi}{\partial n}, \quad \nabla\phi \to 0, \quad R \to \infty, \\ [I]: \phi = 0, \quad \dfrac{\partial\phi}{\partial t} = 0, \quad t = 0, \end{cases} \tag{5}$$

where $\frac{\partial}{\partial n}$ denotes the normal derivative, n is the unit normal vector that points inside of floating body, $\dot{\xi}_k(t)$ represents the six degrees of freedom velocities, and n_k is the unit normal vector of k modal.

Green's function method is usually adopted to solve the above problem. Based on the frequency domain potential theory method, the third Green's formula yields

$$C(p)\phi(p) = \frac{1}{4\pi}\iint_{S_{\mathrm{B}}}\Big(G(p,q)\frac{\partial\phi(q)}{\partial n_q} - \phi(q)\frac{\partial G(p,q)}{\partial n_q}\Big)\mathrm{d}S_q, \tag{6}$$

where $C(p)$ denotes the solid angle, and $G(p, q)$ is the free surface Green's function,

$$G(x,y,z;\xi,\eta,\zeta)\frac{1}{r}+\frac{1}{r_1}+2kPV\int_0^{\infty}\frac{1}{m-k}\mathrm{e}^{m(z+\zeta)}\mathrm{J}_0(mR)\mathrm{d}m-2k\pi\mathrm{i}\mathrm{e}^{k(z+\zeta)}\mathrm{J}_0(kR), \tag{7}$$

in which $p(x, y, z)$ is the field point, and $q(\xi, \eta, \zeta)$ is the source point. $R=\sqrt{(x-\xi)^2+(y-\eta)^2}$, $r=\sqrt{R^2+(z-\zeta)^2}$, $r_1=\sqrt{R^2+(z+\zeta)^2}$, and $\mathrm{J}_0(X)$ denotes the Bessel function. The radiation potential and diffraction potential could be obtained after solving the boundary integral equation (6). No matter in the linear frequency domain or the time domain theory, the solutions are well developed in Ref. [11]. Combining the Bernoulli's equation and further integrating over the wetted surface of floating body S_{B}, the fluid hydrodynamic forces or moments in the relevant direction are expressed as

$$F_i=-\rho\iint_{S_{\mathrm{B}}}\frac{\partial\phi}{\partial t}n_i\mathrm{d}S. \tag{8}$$

Investigating into the interaction between waves and floating body, the second-order potential is generally considered at most. The mean wave drift force from the steady part of second-order components can be treated as a static force. In practice, the mean wave drift force is simply represented only by the first-order potential. Normally, it can be directly calculated after the first-order potential is obtained. The integral expression of the mean drift force by the near-field method is defined by

$$F_i^{\mathrm{drift}}=\frac{\rho g}{2}\int_{l_{\mathrm{W}}}\zeta_{\mathrm{r}}^2n_i\mathrm{d}l+\frac{\rho}{2}\iint_{S_{\mathrm{B}}}|\nabla\phi|^2n_i\mathrm{d}S+\rho\iint_{S_{\mathrm{B}}}\left|x\nabla\frac{\partial\phi}{\partial t}\right|^2n_i\mathrm{d}S,$$

where l_{w} and ζ_{r} denote the water level and the relative wave height, respectively. A random wave load is regarded as the superposition of regular wave load with different frequencies, which is obtained by decomposing the wave spectrum on frequency.

The hydrodynamic performance of typical offshore floating wind turbine is related to the different forms of foundations floating in waves. The gravity center of spar type foundation is lower than its center of floatation. The wave load and motion of spar type foundation with deep draft are smaller in the vertical direction. Thus, it shows better performance of heave than semi-submersible foundation. However, it has worse performance of roll and pitch for the contribution of small water plane to its stability. Additionally, the vortex-induced vibration of spar induced by currents must be considered in design. The TLP type floating foundation possesses good performance of heave and roll. However, the tension mooring system is quite complicated, and the tension forces on the leg are greatly influenced by the currents. Resonance motion easily occurs at the nature frequency of superstructure and mooring system. The semi-submersible foundation with a smaller draft is easily dealt with during transportation and installation.

3.3 Mooring

The mooring system is very important in the integrated design of offshore floating structures. Cable and riser system is also one of the most important systems in ocean petroleum exploitation system and wind energy plant. They are extremely slender and flexible in the form of pipe with small scale. The hydrodynamic loads should include the influence of fluid viscosity such as vortex shedding. The influence due to waves can be neglected. Generally, in the dynamic analysis of mooring lines, bending moment and shearing force can be neglected, while they should be considered in the dynamic anallysis of risers.

In static analysis of mooring systems, the forms of mooring lines and tension in equilibrium state are studied. The static analysis is often adopted in initial design for its convenience. In dynamic analysis of mooring systems, dynamic response of mooring system under complicated environmental loads is investigated so as to judge whether the designed system meets the requirement of positioning and the tension acting on mooring lines is within the allowable range or not.

The methods of dynamic analysis for mooring systems are categorized into the frequency domain method and the time domain method. The frequency domain method is from the perturbation method. All of the nonlinear terms are linearized, and the dynamic quantity is regarded as a small perturbation quantity in the static equilibrium position, and the mass, the added mass, and the stiffness are assumed to be constants. As for the time domain method, all of the nonlinear terms are taken into account. The terms of mass, damping, stiffness, and load are recalculated at each time step.

Mainly, there are three time domain methods for mooring line dynamic analysis, the multi-rigid-body method, the lumped mass method, and the finite element method (FEM). The latter two are widely used. The multi-rigid-body method can simulate the geometric configuration of the lines approximately while keeping its mass distribution. In the lumped mass method, all the external forces are assumed to act on the nodes connected by springs. It is conducive to simulate the mooring line systems with buoys or uneven mass distribution. In the FEM, the finite elements are used to simulate the geometric configuration of flexible parts and tension distributions. It is of high accuracy of solution.

By discretizing the mooring lines, the dynamic equilibrium equation[11] of finite element systems is written as

$$R^{\mathrm{I}}(r,\ddot{r},t)+R^{\mathrm{D}}(r,\dot{r},t)+R^{\mathrm{S}}(r,t)=R^{\mathrm{E}}(r,\dot{r},t), \tag{9}$$

where R^{I} is the inertial force including mass force and added mass force of mooring lines, R^{D} is the damping force which contains internal damping and hydrodynamic damping, R^{S} is the counter force acting on mooring lines also called the mooring line tension, and the exciting force R^{E} includes gravity force, buoyant force, forced displacement due to the motion of offshore floating structure, wave loads, current loads, and external forces acting on any nodes. Here, r, $\dot{r}$, and $\ddot{r}$ represent the displacement, the velocity, and the acceleration of line element, respectively. Equation (7) is just a general expression, if it is a nonlinear problem. The nonlinear terms related to geometrical nonlinearities of mooring lines, material nonlinearities, nonlinear boundary condition, and nonlinear external loads should be introduced. The time domain FEM with good applicability has high accuracy. It has been rapidly developed and widely used in recent years. Chen[12] elaborated the nonlinear interaction between the offshore floating structure and mooring system and established the FEM numerical model with 6-DOF. The model was validated and verified by comparing the numerical simulation of the one-point mooring model with the experimental data, and further investigation and application of the numerical model were also carried out. Meng et al.[13] established the FEM in the time domain for mooring lines made by arbitrary materials, and campared the mooring performance of three common types of mooring lines.

4 Coupled dynamic analysis of interaction between floating wind turbine and wind-wave-current-system

The difficulty of dynamic analysis of the floating wind turbine reflects on the combined effect of the wind, wave, current, as well as the aerodynamic-hydrodynamic-structural dynamic problems. Even in the flow field with the same environmental condition of wind, wave, current, and flow field around offshore floating wind turbines in different forms or different scales may show the significant characteristic such as invisid flow and viscosity flow. For the same floating wind turbine system in the cases of working and survival, the investigation methods and approaches are of great difference. Even in the analysis and simulation by the CFD method, the difficulties about the size of the computation domain and meshes in air-water two-phase flow, the generation method of numerical wave, the stability of non-linear calculation, the scale effect, and calculation of the wind turbine and floating foundation, the computation time step and wave period, and the time length of random wave actions, are still needed to be studied and overcome. Till now, there has been no universal method which can deal with all the problems above. Presently, the suite method being developed is the combinations of various theories and means according to the different flow characteristics around structures. Then, the coupled dynamic analysis of floating wind turbine system and wind-wave-current for various working and survival cases are carried out.

In general, the analysis method for the forces acting on the upper part of floating wind turbine above water is similar. However, the method for hydrodynamic interaction is different due to under-water part in different forms and scales.

If the majority of the under-water part is in the form of slender bars, the loads are relatively easy to calculate, but for the floating foundation with large scale in waves, the damping has memorial characteristics, and the motion equations of the mooring floating foundation in the combined condition of wind-wave-current can be written as follows[14]:

$$\begin{aligned}&\sum_{j=1}^{6}\Big((M_{kj}+A_{kj}(\infty))\ddot{\xi}_j(t)+\int_{-\infty}^{t}\dot{\xi}_j(\tau)K_{kj}(t-\tau)\mathrm{d}\tau+B_{\mathrm{v}kj}\dot{\xi}_j(t)+C_{kj}\xi_j(t)\Big)\\&=F_j(t)+F_j^{\mathrm{W}}(t)+F_j^{\mathrm{C}}(t)+F_j^{\mathrm{M}}(t),\quad k=1,2,\cdots,6,\end{aligned}$$

where M_{kj} denotes the generalized mass of floating foundation (including the rotational inertia), $B_{\mathrm{v}kj}$ denotes the viscosity damping coefficient of the system, C_{kj} denotes the restoring force coefficients, $A_{kj}(\infty)$ denotes the generalized added mass corresponding to the infinite frequency, and $K_{kj}(\cdot)$ denotes the retard function. The generalized added mass corresponding to the infinite frequency and the retard function can be obtained from the linear frequency domain results by use of inverse Fourier transform, or solving time domain equations directly. $F_j(\mathrm{t})$ denotes the encounter wave load including second-order forces. If the random wave force is considered, it can be derived by the superposition of various decomposed frequencies from the spectrum. $F_j^{\mathrm{W}}(t)$ denotes the wind load caused by the average speed and fluctuation speed of wind, and the time series of wind with fluctuation speed can be obtained by the Fourier transform of the gust spectrum. $F_j^{\mathrm{C}}(t)$ is generally considered as the constant force due to sea currents. $F_j^{\mathrm{M}}(t)$ is the force of the mooring system acting on the floating structure. When the dynamic analysis is carried out, the mooring line can be discretized into a series of elements, and the motions of elements are regarded as unknown variables moved to the left side of equation. The newmark-β method or the Runge-Kutta method is often applied to solve the time domain equations[15].

Equations (5)–(8) indicate that the diffraction force and radiation force are regarded as taking the assumption of linear small amplitude waves. The hydrodynamic forces are obtained through the pressure integral on the average wet surface. Therefore, the formula is a simply dynamic analysis equation for the coupled interactions of wind-wave-current and offshore floating wind turbine system with linear assumptions. The method above is suitable for engineering with the virtues of simple and quick calculation. For the large amplitude motions of floating foundation in the severe sea conditions, nonlinear hydrodynamic forces including the incidental forces, radiation forces, diffraction forces, and restoring forces, should be considered by the pressure integral on the transient wet surfaces.

When the offshore floating wind turbine system is oscillating with small amplitudes, the motion of turbine can also be regarded as oscillating in a small amplitude versus the equilibrium position. The loads of turbine acting on the floating system can be calculated approximately with proper correction. When the floating wind turbine system moves with large amplitudes in the severe working conditions, the tower on the floating foundation moves with it, the wheels of wind turbine rotates so that the encountered wind speed and wind directions change, and eventually the loads of the turbine acting on the system change greatly.

For this condition, the accurate time series of loads of wind turbine acting on the floating system is needed so as to completely coupling simulate and analyze the interaction between the floating wind turbine system and the wind-wave-current. The elastic response of structure should be considered because the tower is tall and the blades of wind wheels are slender. Presently, it becomes important to completely coupled analyze the floating wind turbine system and wind-wave-current in the time domain. Recently, Withee[16], Lee et al.[17], Wayman[18], and Wayman and Sclavounos[19] have conducted and developed the coupled calculation programs both in the frequency domain and the time domain pointing for TLP type and spar type offshore floating wind turbine systems. National Renewable Energy Laboratory has conducted the coupled dynamic analysis of aerodynamic-hydrodynamic-structural completely. Sufficiently considering environment flow and the scale of the turbine, choosing some comprehensive approaches with suite theoretical method and numerical means that according to the corresponding flow characteristics, it has become a research trend to accurately coupled analyze the dynamics of aerodynamic-hydrodynamic-structural.

5 Conclusions

The offshore floating wind turbine system, an important equipment of wind farms on sea, is a critical tool for the development of ocean green energy. The topic of research and design for the offshore floating wind turbine system is hot and difficult. The present paper aims at the different styles and characteristics of offshore floating wind turbine systems, combining the hydrodynamics progress of ocean engineering. The wind loads, current loads, wave loads, and dynamic loads of the mooring system are analyzed. The key techniques used in the coupled calculation for the offshore floating wind turbine systems with the wind-wave-current in different conditions are investigated. It is a difficult and crucial problem to obtain a comprehensive analysis of the aerodynamic-hydrodynamic-service system-structure for the coupled effect in an offshore floating wind turbine system in future. The environment flow flied, scales of offshore floating wind turbine system, reasonable utilization of theories, and numerical means should be well considered in advance to accurately analyze the coupled effects of the aerodynamic-hydrodynamic-control-structure.

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