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Analysis of Platform of an Offshore Wind Turbine

Zhang Wei and Liu Jie
College of Materials Science and Engineering, Shenzhen University, Shenzhen 518060, P.R. China

***Abstract*—This study investigates the feasibility of various platforms that support a floating wind turbine. Both theoretical and experimental studies are described. In the theoretical portion, the geometry of platforms with differing configurations is modelled. The hydrodynamic coefficients were derived using WAMIT (Wave Analysis at MIT). An equation of motion was developed that incorporated these coefficients. The computer code FAST (Fatigue, Aerodynamics, Structures, and Turbulence) was used to add the effects of wind turbine and wave loads. In the final step, the wind turbine motion was calculated for six degrees of freedom with and without aerodynamic loads. In the experimental part, a water channel was used. A wide range of waves with different amplitudes and frequencies were generated within the channel. To verify the theoretical results, various model platforms were constructed and the hydrodynamic coefficients were derived to compare them with theoretical results. Finally, a comparison was made of platform configurations with different aspect ratios and designs. It was found that a submerged platform has less movement compare with a surface-based platform with the same shape.**

***Index Terms*—offshore wind turbine, load analysis, hydrodynamic coefficients, dynamic analysis**

I. INTRODUCTION

Wind power is among the fastest growing renewable power generation methods. Wind energy can be generated without pollution and it is inexhaustible. According to the U.S Department of Energy, in 2012, wind energy became the number one source of new U.S. electricity generation for the first time – representing 43 percent of all new electric additions and accounting for $25 billion in U.S. investment. Last year, over 13 gigawatts (GW) of new wind power capacity were added to the U.S. grid – nearly double the wind capacity deployed in 2011. This tremendous growth helped America's total wind power capacity surpass 60 GW at the end of 2012 – representing enough capacity to power more than 15 million homes annually, or as many homes as in the states of California and Washington combined. The country's cumulative installed wind energy capacity has increased more than 22-fold since 2000. One issue comes to the mind in the time of grid connection of wind turbines. In the case of using synchronous generators, proper selection of master or slave generators is critical when a smart grid is around [1] which should be taken care of. Furthermore, offshore wind turbines impact the harmonic levels through their emission. In addition, they impact the resonance frequencies of the grid due to the presence of large amounts of capacitance in forms of underground cables and capacitor banks [2]. In a recent study Presented by Rad *et al*. [3] optimum capacity of a wind farm to cooperate with a hydro-storage have been discussed that can be utilized in maximizing the energy output of wind turbines with various platforms.

The first modern wind turbine was built in 1887 in Scotland. Since then considerable research has been done to improve different aspects of them. As wind turbines became more complex, new problems emerged. A significant problem was the lack of suitable land to erect wind turbines. In order to solve that problem, it has been suggested building them offshore. The offshore wind turbine concept was first introduced by Professor William E. Heronemus at the University of Massachusetts in 1972. As of 2013, there are no offshore wind farms in the United States, but projects are under development along the coast lines that include the Atlantic and Pacific Oceans and the Great Lakes. Recently, researchers considered peripheral issues about offshore windfarms such as protection of offshore power transmission lines that enhances the employment of windfarms [4]. Moreover, as in a conventional power plant, a wind power plant must ensure that the quality of the power being delivered to the grid is excellent [5].

There are numerous advantages in using offshore wind energy.

The wind tends to blow more strongly and consistently, with less turbulence intensity and there is smaller shear at sea than on land.

The visual and noise annoyances of wind turbines can be avoided if the turbines are installed a sufficient distance from shore.

Vast expanses of uninterrupted open sea are available and the installations will not occupy land, interfering with other land uses.

On the other hand, there are also several disadvantages that include, a higher capital investment is required for offshore wind turbines because of the costs associated with modification of the turbine and the added complications of the foundation, support structure, installation, and decommissioning. Storage of the wind energy in enormous pump storage units can increase the capital cost of installation, but can change the production cycle of the combined unit into a more reliable complex

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[3]. Furthermore, offshore wind turbine can be analysed using state estimation methods, which can be used to obtain its running state, including several aspects that cannot be easily obtained using other methods [6].

Offshore installations are less accessible than onshore installations, which raises the operational and maintenance costs and possibly increases the down time of the machines.

Not only do offshore wind turbines experience environmental loading from the wind, but they must also withstand other conditions, such as hydrodynamic loading from waves and sea currents. As a result, the complexity of the design increases. It was suggested that novel method could be used for the fabrication of the platform.

Offshore wind turbines have three main elements: the wind turbine (the main structure), the platform and the mooring lines. The main structure comprises tower, rotor and rotor blades, and nacelle with drive train. The drive train components are gearboxes, high-efficiency permanent magnet machines usually of axial-flux type [7], [8] for direct-drive applications, and coupling and brake. The platform supports the wind turbine and limits its motion in all six degrees of freedom. In order to be able to design the platform, we need to know the force which is exerted on the platform by the wind turbine, the sea waves and the mooring lines. This force can induce some harmonics into the generated power which can affect the local marginal price and increase the electricity cost for the final customers [9]. In a study conducted by Gharghabi *et al*. [10] it was shown that external forces injected to the platform might cause irreversible and detrimental influence on metallic parts which should be considered when designing the offshore platforms. This concept has been considered in this study which will be discussed in simulation setup.

Stability of the platform of a floating wind turbine can be achieved by three different methods. These methods include stabilizing from the water plane area, from the ballast and from the mooring lines. Each of these methods will be discussed in this thesis.

Forces on the wind turbine are mainly due to the wind. Numerical models based on finite element method (FEM) are widely employed to characterize the engineering structures such as wind turbines. Also, the meshless peridynamic method gains popularity recently in structural analysis and damage mechanics [11], [12]. Masoomi [13] suggested to calculate the aerodynamic forces on the turbine by using the computer code FAST (Fatigue, Aerodynamics, Structures, and Turbulence), which was developed at NREL (National Renewable Energy Laboratory) and is publicly available. The first step in the computational procedure is to model the wind turbine with this software. In these studies, the NREL 5-MW wind turbine, which represents a typical state of the art multi megawatt turbine, was used as the model. Next the environmental conditions in which the wind turbine is going to operate were prescribed. Premier among the parameters that are important is the wind speed. Also, it should be noted whether the wind is steady or turbulent. This information allows the software to determine the aerodynamic force on the turbine.

The wave loads were calculated using the computer code WAMIT (Wave Analysis at MIT). The first step in this load calculation is to model the geometry of the platform. The geometry can be described in two ways. One method is to represent the platform by an ensemble of flat quadrilateral panels. In the second method the platform's geometry may be represented by an explicit analytical formula. Next the wave condition must be prescribed. The waves may be regular or irregular and periodic or non-periodic. Also, the free surface must be specified as an input to the software. This is especially important when extreme waves need to be modelled and non-linear effects are not negligible. After all of this the software may be run to produce the results.

A subroutine was written for the calculation of the force from the mooring lines. The inputs for the subroutine are: the elastic modulus of the mooring line material, the water depth and the angle of each line.

Finally, another module was constructed in order to calculate the motion of the whole system in the time domain. The hydrodynamic and aerodynamic forces and the force from the mooring lines are inputs to this subprogram as are the mass, damping and stiffness matrices. Researchers concluded that in order to get accurate output, results should be mesh independent.

In addition to the simulation results, a series of experiments were conducted in order to verify the results. The experiments were performed within a water channel located in the laboratories of the Department of Mechanical, Industrial and Manufacturing Engineering (MIME)at the University of Toledo. A wide range of waves with different amplitude were generated. Also several scale model platforms were built and hydrodynamic coefficients were measured for them.

A. Modelling the Offshore Wind Turbine

The offshore wind turbine consists of three parts; the floating platform, the wind turbine and the mooring line. In this paper, each component is modelled separately and in the final stage all of the components will be considered together, and the voltage stability of the output power has to be ensured [14], [15]. In this section, details of the chosen wind turbine will be examined. Also, in the relevant sections different platforms and the mooring line which were chosen to be modelled will be considered.

At this step we want to know how changing different parameters will affect the platform movement. One of the important factors which is crucial in determining the platform movement is whether the platform is submerged or whether it is surface piercing. In first case the loads on the platform will be reduced but on the other hand if the structure pierces the wave free surface it will gain stiffness and stability. The other important element which affects the movement of the platform is depth of the sea into which the wind turbine will be installed (Fig. 1).

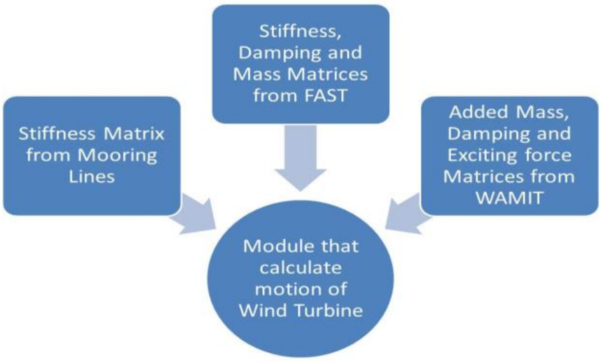

Figure 1. Schematic overview of simulation

In order to simulate platform motion, we need to know the wind turbine properties. In order to acquire that information, we have to run FAST for a particular operating point. FAST will give us mass, damping and stiffness matrices. Also, from using WAMIT, we have the added mass and damping matrices for the platform. Finally, by adding the effects of the mooring line we could solve the equation of motion for the wind turbine.

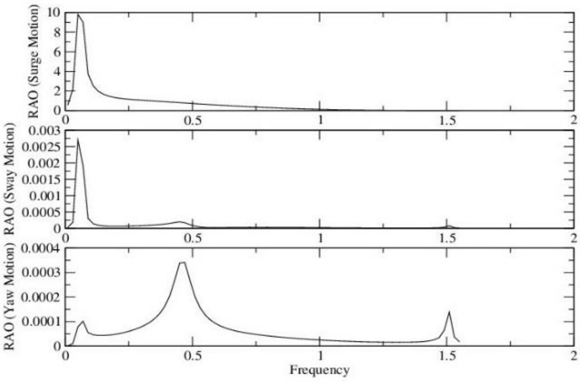

Figure 2. Submerged platform in 60 m depth

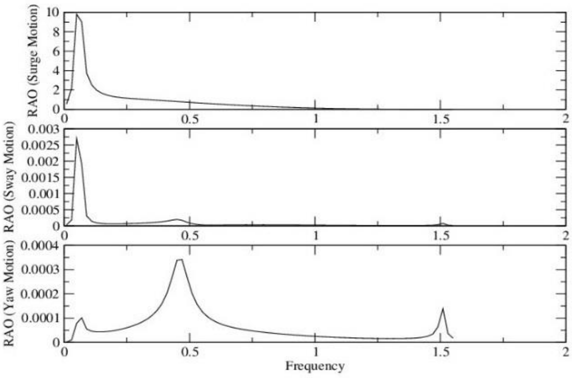

Figure 3. Submerged platform in 150 m depth

In order to obtain this information, the FAST code was run to get the linearized mass, damping and stiffness matrices. The response was nondimensionalized by dividing the motion by wave amplitude. And Response Amplitude Operator (RAO) in x and y direction also rotation around z direction were presented in Fig. 2-Fig. 9.

In the current simulations two platforms were analysed. Also their movement was simulated for three depths: L=60 m, 150 m and 450 m.

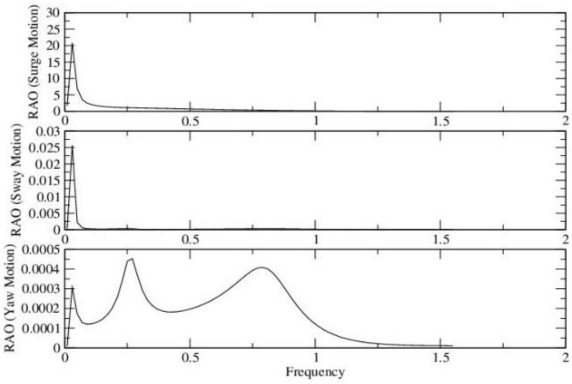

Figure 4. Submerged platform in 450 m depth

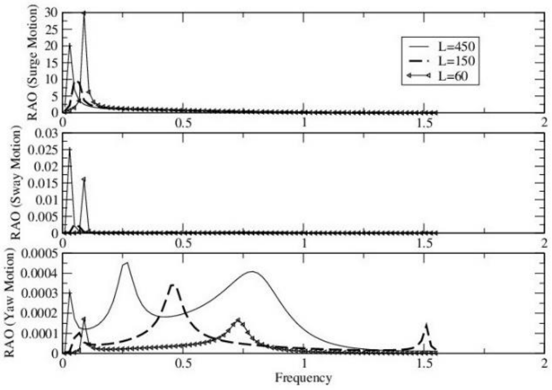

Figure 5. Submerged platform

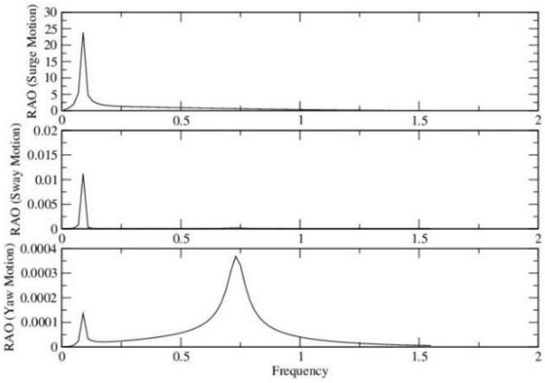

Figure 6. Surface platform in 60 m depth

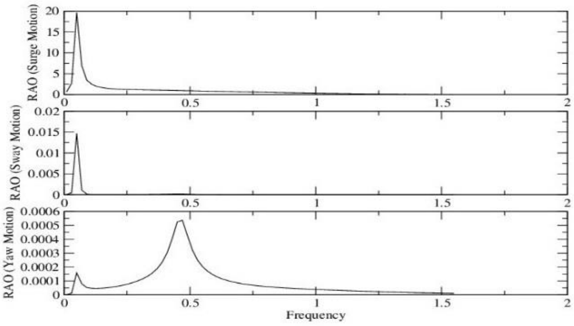

Figure 7. Surface platform in 150 m depth

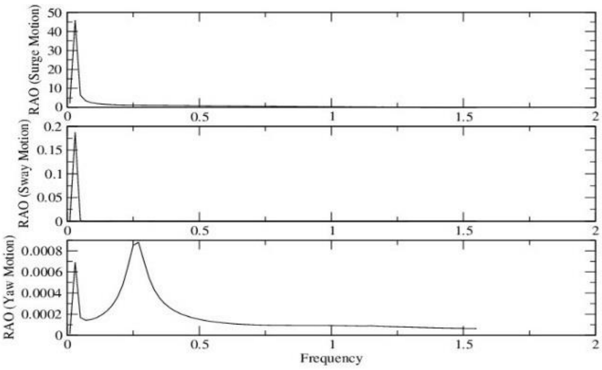

Figure 8. Surface platform in 450 m depth

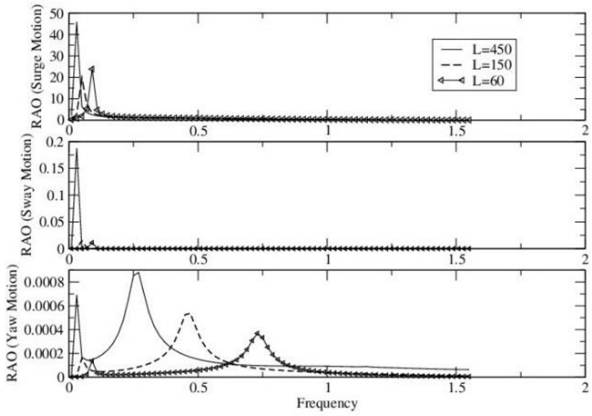

Figure 9. Surface platform

II. DISCUSSION

As we can see in the graphs, a submerged platform has less movement in comparison with a surface-pierced platform. The reason is that the wave loads on submerged platform are less, so the motion will be less. The problem of the submerged platform is that its stability is not assisted by the waterplane area, so it needs to have stiffer mooring lines.

Also, it is obvious that the maximum response occurs at the highest frequency, as the depth of water increases. The justification of that is the stiffness of the mooring line will decrease as we increase the depth, so at larger depth the maximum amplitude occurs at a higher frequency.

III. CONCLUSION

In the paper, the three steps method has been developed and used. First FAST used to derive the wind turbine properties. Also it is used to derive the aerodynamic force on the wind turbine. Second, WAMIT was used to derive the hydrodynamic coefficients of the platform. Finally, by using these data, the equation of motion for offshore wind turbine was solved. Also for verification of the data which were derived by WAMIT, several experiments were done.

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