Aerelastic Behavior of Offshore Wind Turbine Airfoil during Typhoon

Nianxin Ren¹, Jinping Ou¹,², Changjiang He¹

1. School of Civil Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China;
2. School of Civil and Hydraulic Engineering, Dalian University of Technology, Dalian, Liaoning, China

ABSTRACT
In this paper, the aerelastic behavior of the wind turbine FFA-W3-211 two-dimensional airfoil in the dynamic stall regime has been investigated during the natural typhoon real time history. What’s more, the interaction between the airfoil stall-induced vibration and the unsteady flow has been effectively taken into consideration. Based on Navier-Stokes equation and k-ω SST turbulence model, the aerodynamic loads acting on the airfoil have been obtained by numerical simulation of the unsteady flow field near the airfoil under large angle of attack. Subsequently, the aerodynamic response of the airfoil can be calculated by embedding structural dynamics Newmark-β codes into the flow solver. Finally, the nonlinear interaction between the airfoil vibration and the unsteady flow can be successfully studied by taking advantage of the moving mesh technique for the simulation of the airfoil dynamic responses. Three kinds of stall-induced vibration have been considered: pitching oscillation, flap-wise oscillation and flap-pitching two degree-of-freedom coupled oscillation. Consequently, the key factors for the wind turbine two-dimensional airfoil aerelastic performance during natural typhoon have been pointed out. Furthermore, the main reasons have been clarified in views of physical mechanism for fluid-structure interaction.

KEY WORDS: Typhoon data; FFA-W3-211 airfoil; fluid-structure interaction; stall-induced vibration; flap-pitching oscillation

INTRODUCTION
As is known to all, the offshore wind farm with its special advantages is developing at an amazing speed through the world. Some European developed countries have built many offshore wind farms and have gained a series of valuable technical and operational experiences. Now, China is actively planning several large offshore wind farm projects in its east coastal areas. With the increase of the rated power for a single offshore wind turbine, the size of the blade is becoming larger and larger. As a result, the performance for the whole blade structure is becoming more and more flexible, which may cause the new challenge for the aerodynamic and aeroelastic design of the huge blade structure to withstand the possible attack of typhoon.

Comparing with normal wind, typhoon has the characteristics of higher wind speed, more serious change of wind direction and larger turbulence intensity. These characteristics may easily cause the stall-induced oscillation of offshore wind turbine airfoils. The stall aeroelastic instability can potentially result in the damage of the whole blade structure. In fact, the flow-field near the airfoil during the dynamic stall process is largely separated and the viscous effect is important. The physical process involves growth and evolution of leading edge vortex structure and their subsequent shedding from the body into the near wake. Therefore, the study on the aerelastic behavior of large offshore wind turbine airfoil during typhoon is a typically complex nonlinear fluid-structure interaction problem.

Many researchers have studied the wind character of typhoon and some others have deeply studied the aerelastic behavior of airfoils, separately. But, so far few researchers do the further study on combining real typhoon field data with the aerelastic behavior of the wind turbine airfoil. For example, Shuyang Cao, Yukio Tamura, et al.(2009) have analyzed the wind characteristics of Typhoon Maemi on the basis of 10 min wind speed samples, which is useful for some practical projects to a large degree. Chaviaropoulos et al. (1999, 2003) have presented a study on stall-induced flap and edgewise oscillation in a stall-regulated rotor by a quasi-steady Onera model as well as Navier–Stokes solvers, but the effects of structural nonlinearity have not been studied. Price and Fragiskatos (2000) have presented a nonlinear stall flutter analysis of a symmetric airfoil, using a nonlinear dynamic stall model by Beddoes–Leishman. Furthermore, based on research achievement of Dunn and Dugundji (1992), Sarkar and Bijl (2008) studied the pitching oscillation model and flap-edgewise oscillation model, using the Onera model to compute the aerodynamic loads in the dynamic stall regime. As is known to all, the two famous semi-empirical dynamic stall models, the Onera model (Tran and Petot, 1981) and the Beddoes–Leishman model (Leishman and Beddoes, 1989), are both based on a large number of experiment data for a certain type of airfoil. Therefore, the two semi-empirical models may both have some limitations for application on different airfoils, that’s because the aerodynamic loads model in the stall regime may be different from airfoil to airfoil.

As the rapid development of CFD technique, a new method, which may break through the limitation of the semi-empirical model and has larger