# Offshore Wind Farm Simulation and Research on Wind Turbine Dynamic Response under Different Yaw Conditions

Yi Liu[1], Yingning Qiu[*,1], Mengfei Li[1], Yanhui Feng[1], Mostafa Bakhoday-Paskyabi[2], Hoang Hai Bui[2]
[1]School of Energy and Power Engineering, Nanjing University of Science and Technology, Nanjing, China
[2]Geophysical Institute, University of Bergen, Bergen, Norway

## Abstract

The complex operating conditions of offshore wind farms and the wake effect caused by the increasing size of wind blades will aggravate the downstream WTs' external loads, which include aerodynamic loads and wave loads, as well as vibration. To explore the wake effect, the load change pattern, and the dynamic response mechanism of offshore WTs under complex operating conditions, this study constructed a multi-turbine offshore wind farm simulation model in FAST.Farm. The multi-turbine offshore wind farm simulation model is constructed based on the positional arrangement of the wind turbines in a real offshore wind farm and the SCADA measurements. Five different incoming wind speed intervals were selected as five different inflow conditions to calculate the mean wind speed and turbulence intensity. The turbulent wind field is also generated by the parameter settings in Turbsim for each condition to simulate the actual inflow conditions. The validity of the simulation model of the multi-turbine offshore wind farm is verified by comparing the wind speed, power, generator speed and pitch angle in the FAST.Farm simulation results with the SCADA measurements. By comparing the changes of each kinetic index quantity of the downstream WT when the upstream WT has no yaw or the yaw angle is 15°, we explore the influence of the wake stream deflection caused by yaw on the dynamic response of the wind turbine. By simulating the distribution of the wake flow of the multi-turbine under different operating conditions, the patterns of how different inflow conditions influence the downstream WT load response are summarized. The results provided in this study are of great significance for optimizing offshore wind turbines' safety and reliability design and realizing wind farms' load-shedding cluster control.

**Keywords: Dynamic response, Offshore wind farm, Wake effect, Wind turbine loads**

## Introduction

Multi-body dynamics methods are often used for accurate nonlinear analysis, and rigid-flexible coupling modeling methods are used. Therefore, multi-body dynamics models are widely used in the analysis of load and structural response of wind turbines. This study aims to explore the load change rules and dynamic response mechanisms of various components of offshore wind turbines under complex working conditions and wake effects. By coupling the wind field model, aerodynamic model, hydrodynamic model, structural dynamics model, control model and wake model, a dynamic coupling simulation model of offshore wind turbines was established.

## Wind Turbine Dynamics Coupling Simulation

In this study, the aerodynamic-hydrodynamic-elastic-control coupled wind turbine dynamics model of a monopile 3.3 MW wind turbine is established in OpenFAST, and a multi-turbine offshore wind farm model is constructed in FAST.Farm. The study also processed and analyzed the SCADA data of a real wind farm, and verified the validity of the model based on the actual wind condition data and blade vibration data. The topology of the wind turbine simulation model is shown in Fig. 1. The model visualization of multiple wind turbines and their flow fields is shown in Fig. 2.

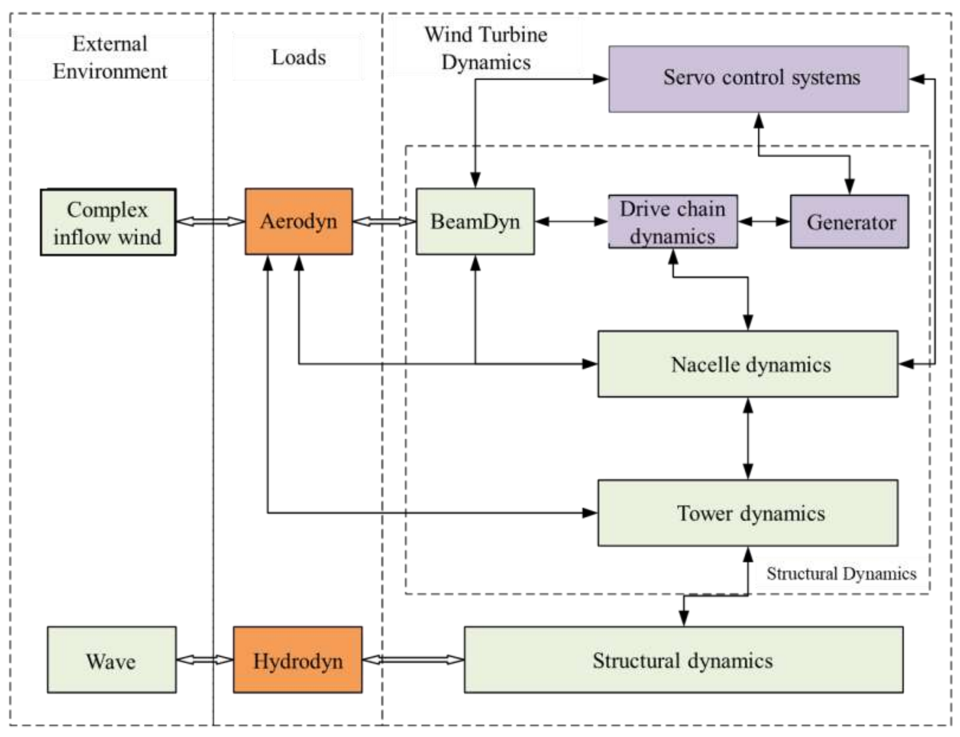


**Fig. 1.** Topology of the wind turbine simulation model

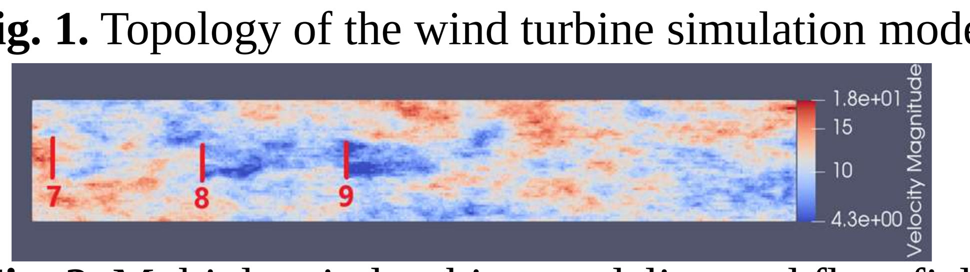


**Fig. 2.** Multiple wind turbine modeling and flow field visualization

## Model Validation

To verify the validity and accuracy of the model, quantitative indexes such as wind speed, power, generator speed and pitch angle are selected in this study to compare and analyze the correlation between the simulation results and the actual SCADA data. Fig. 3 shows the simulation results of each quantitative index and the relative error of SCADA data for the three wind turbines under different incoming wind conditions. The trends of average wind speed, power, generator speed and pitch angle of the simulation results and SCADA data are in good agreement, and the larger errors appear in the low wind speed section, while the relative errors gradually decrease with the increase of wind speed.

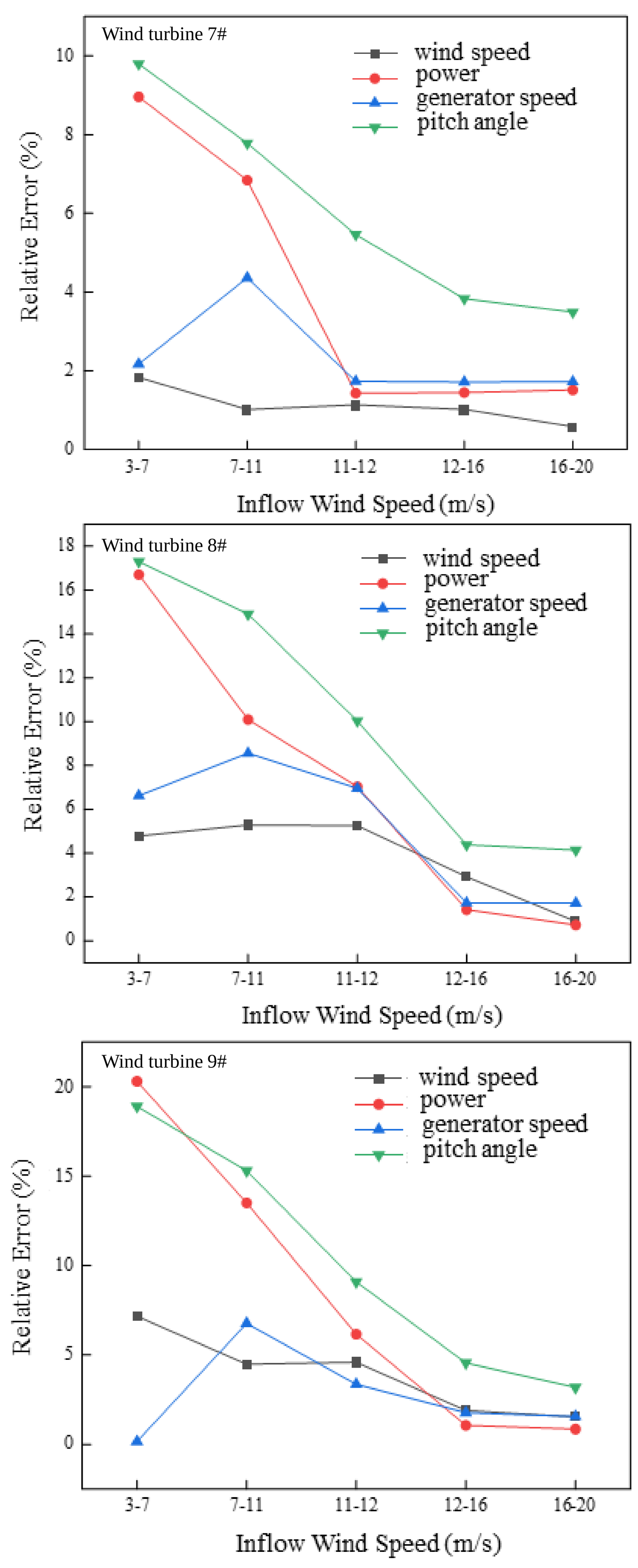


**Fig. 3.** Relative errors of three wind turbines under different inflow wind speed intervals

## Results and Discussion

By comparing the changes in various dynamic indexes of the downstream wind turbine when the upstream turbine has no yaw and when the yaw angle is 15°, the impact of wake deflection caused by yaw on the downstream wind turbine dynamic response is explored. It can be seen from Fig. 4 that after the upstream wind turbine yaws, the power of the downstream wind turbines will increase by approximately 9.09% and 8.43% respectively. This is because the yaw angle of the upstream wind turbine causes wake deflection, and the downstream wind turbine is located in part of the wake area of the upstream wind turbine, which increases the inflow wind speed, thereby causing an increase in power. It can be seen from Fig. 5 that the changing trends of the wind turbine aerodynamic load of the downstream wind turbines are consistent with the power, and the wake deflection will significantly increase the vibration amplitude of the load of the downstream wind turbine.

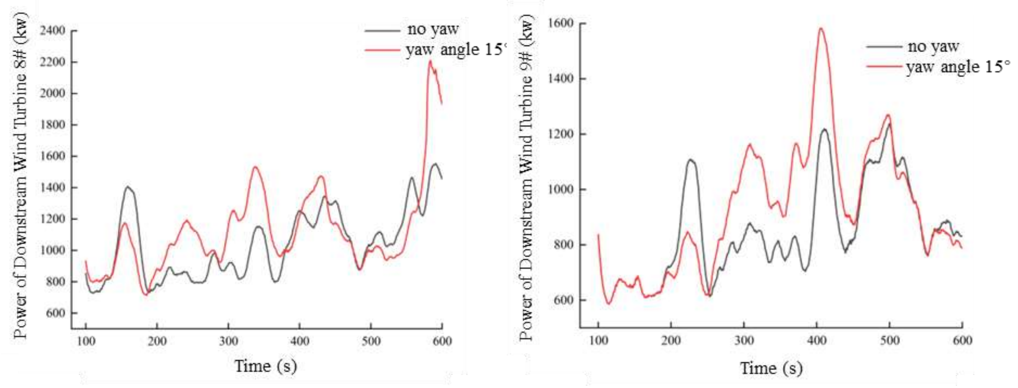


**Fig. 4.** Power comparison of downstream wind turbines 8# and 9# when the upstream wind turbine has no yaw and 15° yaw

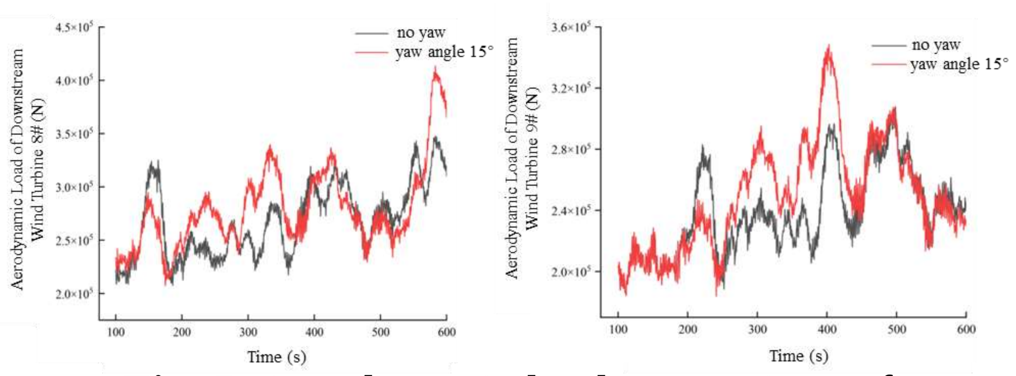


**Fig. 5.** Aerodynamic load comparison of downstream wind turbines 8# and 9# when the upstream wind turbine has no yaw and 15° yaw

## Conclusion

To investigate the wake effect and the load change rule and dynamic response mechanism of offshore wind turbine under complex working conditions, a multi-body dynamic simulation model of aerodynamic-hydrodynamic-control-structural coupling of monopile offshore wind turbine is established in this study. The validity of the model is verified according to the actual data, and the influence of the complex working conditions on the load of the wind turbine considering the wake effect is investigated. A multi-turbine model of offshore wind farm is established in OpenFAST, and the load response of multi-turbine under wake effect and complex working conditions is analyzed by simulating different incoming wind conditions. By analyzing the load response of the downstream wind turbines under different incoming wind conditions such as different wind speeds, wind shear effect and turbulence intensities, as well as the variation of the distance between the wind turbines, the kinetic response and wake effect mechanism are explored. Furthermore, by simulating different yaw angles of the upstream wind turbines, the power and fatigue load variation rules of multi-turbine were analyzed. The results of this study are of great practical significance for the realization of cluster control optimization for offshore wind farm load reduction and efficiency.

Contact
Name: Yi Liu
Organization: Nanjing University of Science and Technology
Email: sibyl_l@njust.edu.cn

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