Predicting the Output Power Uncertainty of an Offshore Wind Turbine Based on Environmental Conditions

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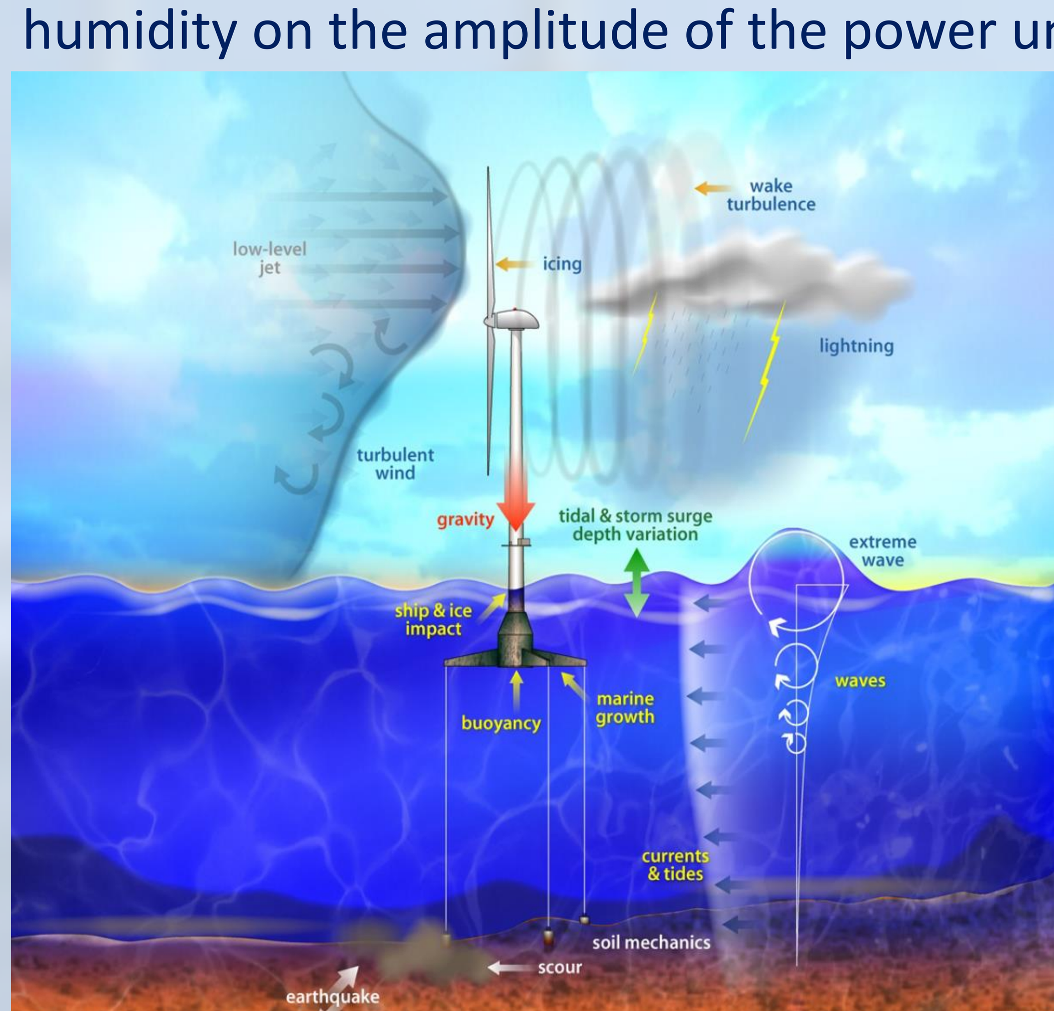
Background and Objectives

New Jersey is targeted to become a leader in offshore wind energy in the US with the recent contract of 1.2 GW in the 1st phase and an ambitious plan to increase the offshore wind energy capacity to 3500 MW by 2030 (Board of Public Utilities, 2018). The booming wind energy sector needs expertise and knowledge to support the design of wind farms, the assessment of project safety and environmental impacts, and the development of efficient system control for the local atmospheric and ocean conditions. This project is designed to provide a tool capable of predicting wind power more accurately in terms of power fluctuations along with mean power. Traditionally, the industry relies on power curves, which are predetermined relationships between turbine output power and wind speed. This kind of power curve is developed by applying the method of bins on wind speeds and output power data. Error bars are also used to indicate uncertainties in estimated output powers. However, quantifying these uncertainties that are originated from site complexities and stochastic environmental conditions is difficult and analytical tools give only rough estimates. Therefore, a tool with high degree of accuracy in wind power characteristics prediction according to environmental conditions helps wind farm operators detecting turbines performance anomalies more easily.

Method

To identify the effects of wind speed and direction, wave height and direction, atmospheric pressure, air temperature, and relative humidity on the amplitude of the power uncertainties, OpenFAST,

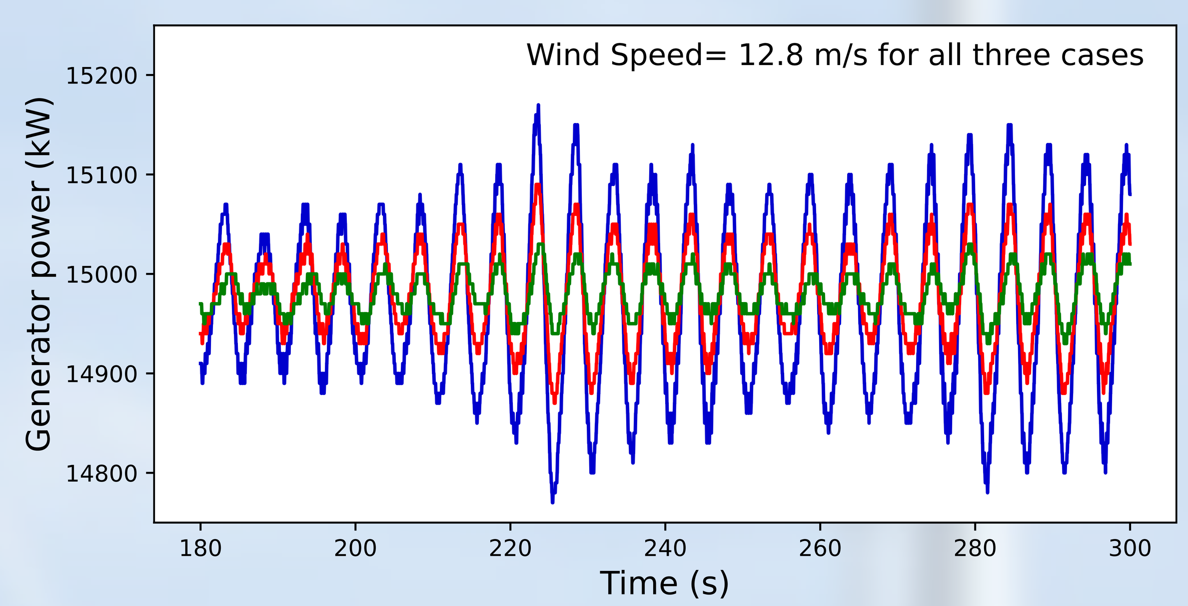


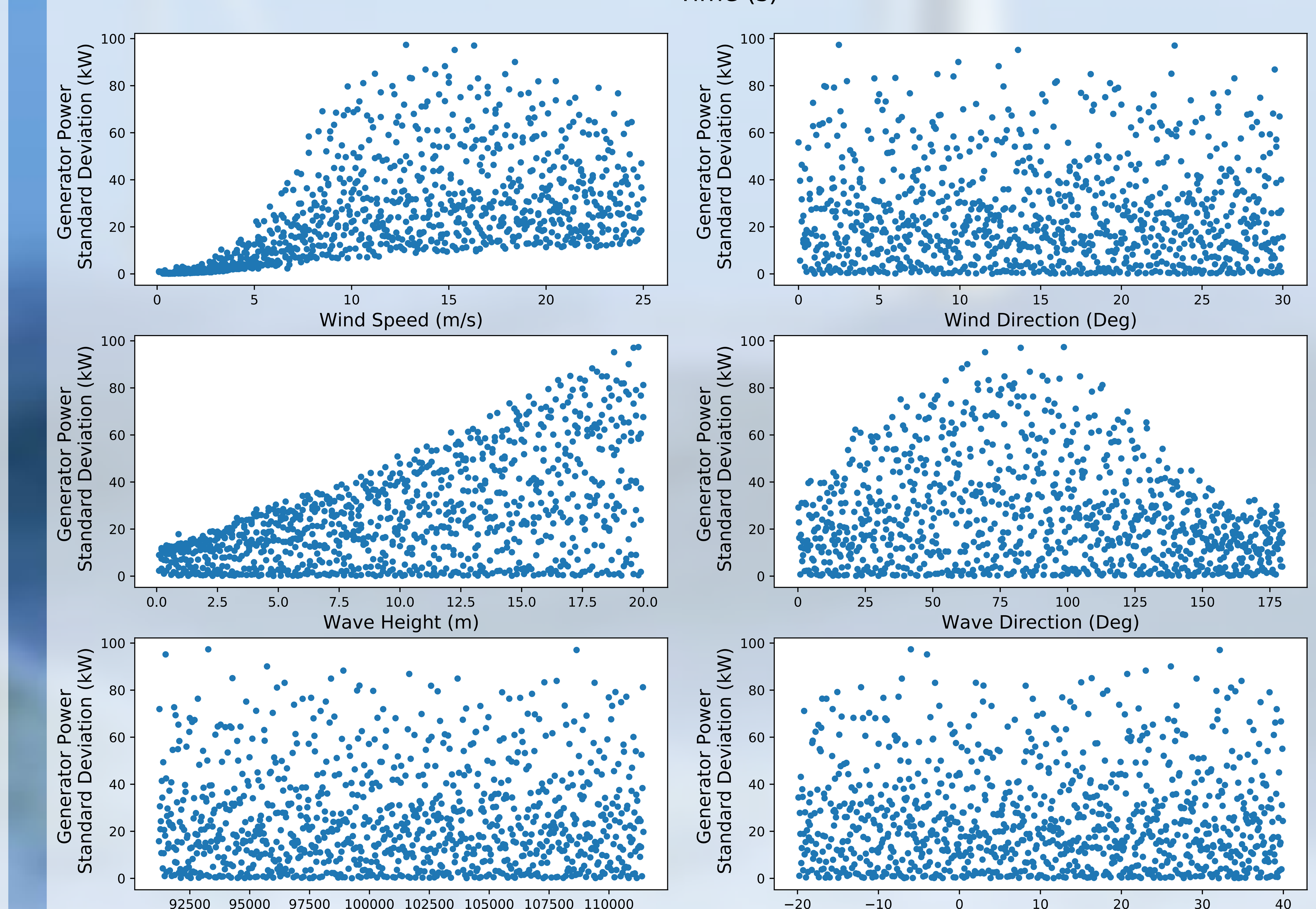
an open source model for transient simulation of the performance of offshore wind turbines, is used. OpenFAST has following modules and all modules are coupled to reproduce nonlinear dynamics of turbines.

- ✓ AeroDyn
- ✓ HydroDyn
- ✓ ElastoDyn
- ✓ ServoDyn

Simulations

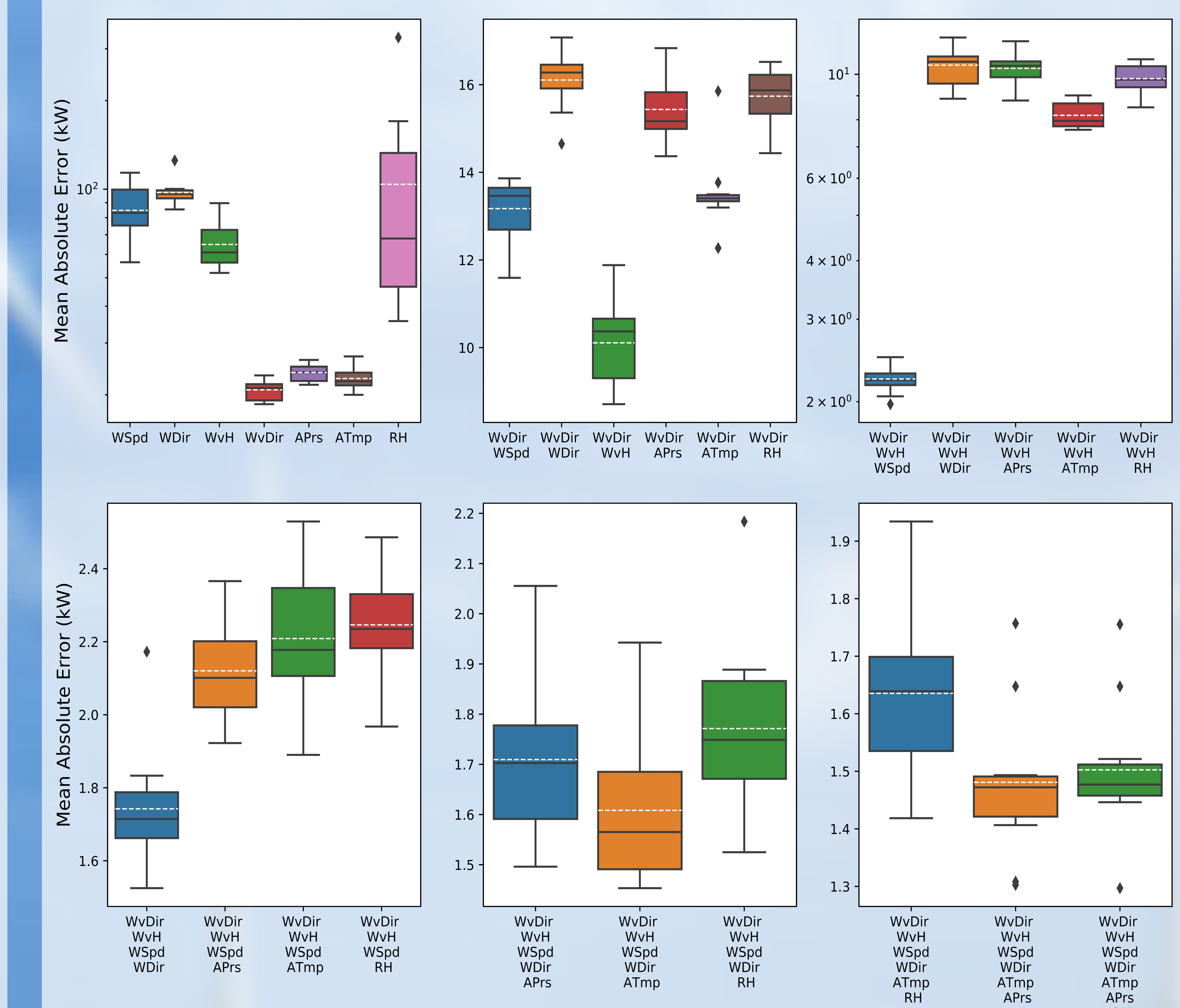
Wide ranges for the mentioned air and sea environmental parameters, specifically for the of New Jersey offshore area, are considered and a large number of sample cases are generated using the Sobol sequences method, which is pseudo-random sample generator. Then, these sample cases are employed as the input data of the OpenFAST for a 15 MW offshore wind turbine. The OpenFAST results are then used as input data to finally predict the power uncertainties based on different operational and environmental conditions. For this purpose, a multivariate data-driven model is developed using machine learning methods. The OpenFAST simulation results show that generator power may have different amplitude of fluctuations though the turbine experiences identical wind speed. The variations of generator power standard deviation versus environmental parameters of wind speed, relative wind direction (yaw misalignment), wave height and direction, and air pressure and temperature are shown below.





Predictive Analyses

To predict the generator power standard deviation based on the environmental parameters, univariate and multivariate models are trained systematically to find the order of importance of input variables. Training and testing models using Kriging method are performed using 10-fold cross validation and mean absolute errors (MAE) of each sub-models are plotted using boxplots shown below. The results show that the model with input of wave direction has the lowest MAE among the univariate models.



Conclusion

The results indicate that the order of importance of environmental parameters in predicting the generator power standard deviation is wave direction, wave height, wind speed, relative wind direction, air temperature, air pressure, respectively. Also, this study shows that although considering air temperature, pressure and relative humidity as input variables increases the accuracy of predictions, this improvement is not statistically significant according to the boxplots. Finally, it should be noted that the proposed method can predict the amplitude of output power uncertainty with a mean relative error of 7%.