16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

A neural network based surrogate model for assessing vibration induced fatigue damage on wind turbine tower

HAO BAI[1*], LUJIE SHI[1†], CHANGWU HUANG[2], DIDIER LEMOSSE[1]

1. Laboratory of Mechanics of Normandy (LMN), INSA Rouen Normandy, Rouen 76000, France [0000-0003-3546-8802]
2. Department of Computer Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China [0000-0003-3685-2822]

* Presenting Author

† Corresponding Author: Lujie Shi, lujie.shi@insa-rouen.fr

Abstract: The vibration-induced fatigue damage is a critical issue for both the structural safety and the producibility of the wind turbine. However, the conventional fatigue assessment based on computational mechanics is usually time-consuming. To overcome this drawback, a surrogate model based on the deep neural network is proposed in this work. The numerical results validate both the effectiveness and the accuracy of the proposed model.

Keywords: Fatigue damage, Residual neural network, Wind turbine tower, Numerical method

1. Introduction

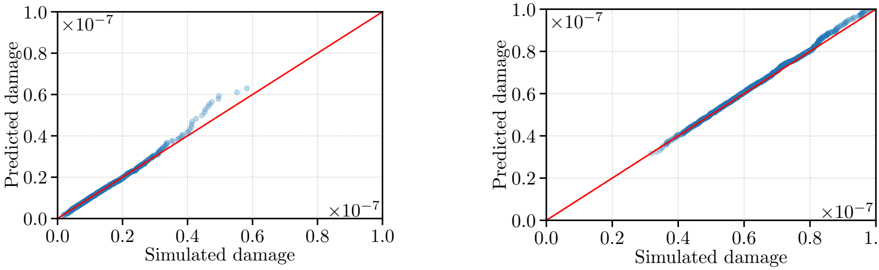
The random nature of the wind actions could cause unexpected fatigue damage and thus reduce the wind turbine's operating lifetime. With the increasing size of wind turbine towers, the fatigue damage induced by the vibrations and cyclic loads becomes more and more crucial. Therefore, a reliable mechanical design is essential for high-rise wind turbines to ensure their operating lifetime. To assess the fatigue damage on wind turbine towers, a probabilistic framework was newly proposed [1]. The concept is based on a combination of deterministic fatigue analysis and probabilistic approach. Therefore, a large number of numerical simulations is required to prepare a dataset for fatigue estimation which is a heavily time-consuming task. To overcome this drawback, we propose a surrogate model for the proposed framework using a deep neural network in this paper.

The model is based on residual multilayer perceptrons (ResMLP) [2] that the skip connections are introduced to an ordinary neural network. The proposed surrogate model is compared to the direct numerical solutions for NREL 5MW reference wind turbine [3] using the simulation tool FAST [4].

2. Results and Discussion

Firstly, the trained model is used to predict the fatigue response of the reference wind turbine under wind conditions with turbulence. The neural network was trained by using the fatigue damage calculated for mean wind speed from [3.0 m/s, 4.0 m/s, …, 25.0 m/s]. The test set was to predict the fatigue damage in the same wind condition except that the mean wind speeds are drawn from [3.5 m/s, 4.5 m/s, …, 24.5 m/s]. These cases of mean wind speed have never appeared in the training dataset nor the validation dataset. Likewise, the number of simulations per mean wind speed is also fixed to 10 000 runs which implies a total of 220 000 numerical simulations in FAST codes. The 10-min cumulative fatigue damages acquired in these numerical simulations are compared to those obtained from the trained neural network. To keep this paper to be brief, only the comparison near cut-in speed (i.e., 3.0 m/s) and cut-out speed (i.e., 25.0 m/s) are graphed in Fig. 1.

The correlation between the predicted damages and the simulated damages proves that the predicted values are mostly conformed to the simulated values of the fatigue damage. Among 10 000 points at each mean wind speed, only tens of points are away from the linearly correlated line (red line).



Cut-in speed: V_{mean} = 3.5 m/s   Cut-out speed: V_{mean} = 24.5 m/s

Fig. 1. Comparison between the predicted values and the simulated values for 10-min cumulative fatigue damage at (a) cut-in speed and (b) cut-out speed

The good accuracy of the trained residual neural network in predicting 10-min cumulative fatigue damage for untested mean wind speeds encourages the author to use it in predicting the fatigue response of the wind turbine tower under stochastic mean wind speeds.

3. Concluding Remarks

In this paper, a surrogate model using a deep neural network with residual learning is developed for assessing the fatigue damage induced by the vibrations. The model implements a 13-hidden-layers neural network with 300 perceptrons on each layer to predict the 10-min cumulative fatigue damage of the NREL 5MW reference wind turbine under wind with turbulence. The reference wind turbine is assumed to generate electrical power normally during a fixed simulated time of 10 minutes.

A sample including 23 000 observations for the training dataset and 5750 observations for the validation dataset is used to train the ResMLP. The accuracy of the predictions from the trained model is assessed by comparing with the numerical results computed directly from FAST simulator. It is demonstrated that the surrogate models can accurately and economically predict the distribution of 10-min cumulative fatigue damage for any mean wind speed in the operating range, i.e., between cut-in speed and cut-out speed. This advantage opens the opportunity to implement the proposed probabilistic framework for fatigue assessment in the wind energy industry in which a quick-response design process is usually required.

References

[1] Bai H, Lemosse D, Aoues Y, Cherfils JM, Huang C: A probabilistic approach for long-term fatigue analysis of onshore wind turbine tower. *14th World Congress on Computational Mechanics*, 2020.

[2] He K, Zhang X, Ren S, Sun J: Deep residual learning for image recognition. *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2015,:770-778.

[3] Jonkman J, Butterfield S, Musial W, Scott G: Definition of a 5-MW Reference Wind Turbine for Offshore System Development. *National Renewable Energy Laboratory (NREL),* 2009.

[4] Jonkman J, Jr. Buhl M: FAST User's Guide. *National Renewable Energy Laboratory (NREL),* 2005.