Study of turbulence intensity effect on the fatigue lifetime of wind turbines

Ismaiel, Amr M. M.
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University | Faculty of Engineering and Technology, Future University in Egypt

Yoshida, Shigeo
Research Institute for Applied Mechanics, Kyushu University : Professor

https://doi.org/10.15017/1906114

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 3, pp.1-2, 2017-10-19. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

3rd International Exchange and Innovation Conference on Engineering & Sciences
Kyushu University, Fukuoka, Japan
October 19-20, 2017

Study of turbulence intensity effect on the fatigue lifetime of wind turbines

Amr M. M. Ismaiel[1,2,*], Shigeo Yoshida[3]
[1]Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan.
[2]Faculty of Engineering and Technology, Future University in Egypt (FUE), Egypt.
[3]Research Institute for Applied Mechanics, Kyushu University, Japan.
[*]Corresponding author email: amrmetwally@riam.kyushu-u.ac.jp

Abstract: *In this paper, the effect of variable turbulence intensities on the fatigue lifetime of wind turbines is studied. Time series aeroelastic simulations were carried on the NREL WindPACT 1.5MW upwind turbine using an open source software FAST. Two turbulence models -von Karman and Kaimal- were used with four different turbulence intensities (1%, 10%, 25%, and 50%). The time series data of the loads were post processed using the tool MLife to estimate the fatigue lifetime of the wind turbine. It is found that high turbulence intensities increase the extreme loadings on the turbine, increase damage equivalent loads, and decrease the estimated lifetime. It is also found that both turbulence models' results agree, there is no remarkable difference between them in the fatigue behavior of the turbine, and gave very close results.*

Keywords: Aeroelasticity, Fatigue, Turbulence, Wind Turbine.

1. INTRODUCTION

The world intention towards renewable resources of energy has increased recently, because of the limitation of the amount of fossil fuels. Among the renewable energy sources, wind energy has a very high potential of development and growth year after year [1]. Wind turbines are the conventional method of converting wind energy into mechanical energy, and then into electrical energy.

Design lifetime for a wind turbine typically is twenty years of operation [2]. One of the most important factors affecting the dynamics of the turbine, is the turbulence of the wind acting on it.

In this paper, the effect of different turbulence intensities on the fatigue behavior of the wind turbine is studied. The importance of this study is to anticipate the fatigue behavior of wind turbines according to turbulence in the wind, and know its effect on the lifetime.

In the following sections, a brief representation of the two turbulence spectral models used for the study, von Karman and Kaimal, will be introduced. Then a comparison between the two models' results. And in the last section, the conclusion of the study will be introduced to summarize the findings of this work.

2. TURBULENCE SPECTRAL MODELS

Motion of the atmosphere varies in both spatial and time domains. Turbulence can be defined as the random and fast fluctuation of wind speeds around its mean value, in a small-time scale. [3] These fluctuations occur in longitudinal, lateral, and vertical directions.

It is a complex process to represent the turbulence mathematically because it is a random process which cannot be simply described by deterministic equations. So, it is more useful to describe turbulence according to its statistical properties; turbulence intensity (TI). It measures the overall turbulence level, and can be defined as;

$$I = \frac{\sigma}{\bar{U}} \quad (1)$$

Where; I is the turbulence intensity, σ is the standard deviation of the wind speed, and $\bar{U}$ is the mean wind speed.

Two spectral models are commonly used to express the spectrum of the longitudinal wind component, denoted by a subscript "u". Those models are the von Karman and Kaimal spectral models. They can be expressed as follows [3,4];

Kaimal:

$$\frac{nS_u(n)}{\sigma_u^2} = \frac{4nL_{1u}/\bar{U}}{(1+6nL_{1u}/\bar{U})^{5/3}} \quad (2)$$

von Karman:

$$\frac{nS_u(n)}{\sigma_u^2} = \frac{4nL_{2u}/\bar{U}}{(1+70.8(nL_{2u}/\bar{U})^2)^{5/6}} \quad (3)$$

Where; $S_u(n)$ is the wind's longitudinal component's spectral density function, σ_u is the longitudinal wind speed's standard deviation, L_{1u} and L_{2u} are length scales with values depending on the surface roughness z_0 and the above ground height z.

The von Karman spectral model can give a better description for turbulence occurring in wind tunnel tests, while the Kaimal model fits better to the atmospheric turbulence [5]. However, the von Karman model is consistent with the analytical formulae, and hence, often used for the correlation.

In this paper, both spectral models are used for the simulation, for the reason of comparison between their results. NREL engineers have developed many software tools to model and simulate the wind turbines. Among those software is the TurbSim [6], a tool which simulates turbulence fields around wind turbines. Different turbulence intensities have been used for the wind field generation to know the effect of the turbulence intensities on the lifetime of a wind turbine. Accordingly, four different random values for turbulence intensities where chosen for the study, including very low turbulence (1%), medium turbulence (10%), high turbulence (25%), and severe turbulence

(50%). Each turbulence intensity was modeled using both the von Karman and Kaimal models, then their results were used as an input to the software tool FAST; an aeroelastic tool for wind turbines.

3. RESULTS AND DISCUSSION

The wind turbine used for the simulation is the NREL WindPACT (Wind Partnership for Advanced Component Technologies) 1.5MW wind turbine. Originally, the WindPACT project aimed for studying the effect of scaling of different rotor configurations on the cost of energy (COE). Four different configurations are available for the WindPACT project; 0.75MW, 1.5MW, 3MW, and 5MW [7]

Aeroelastic simulation is performed on the wind turbine using FAST. Wind velocities and wind loads time series are generated. This simulation is performed for each turbulence model and for each turbulence intensity.

The simulation results made by FAST are then postprocessed using MLife. MLife is a MATLAB® based tool which can estimate the fatigue behavior of wind turbines. Damage equivalent loads and time until failure for aerodynamic loads' time series are calculated for each turbulence model and for the four different turbulence intensities.

The material properties of the WindPACT 1.5MW wind turbine are not completely defined, some data are defined but some information is missing. The ultimate loads for the simulation were chosen based on the WindPACT maximum loading data [8], while the blade and tower materials are not specified, so, the blade material is assumed to be made of composite material, using two values of Wohler exponent (m) [9] of 8 and 10. And the tower is assumed to be steel, with a Wohler exponent of 3.

In the following tables, the lifetime until failure for the chosen S/N curves for 1% and 50% turbulence intensities using the von Karman spectral model will be displayed. L_Ult is the ultimate load for each S/N curve, and m is the Wohler exponent.

Table 1. Lifetime until failure (s) for various S/N curves (von Karman model – 01% TI)

		RootFxc1 (kN)	RootFyc1 (kN)	RootMxc1 (kN·m)	RootMyc1 (kN·m)	TwrBsMxt (kN·m)	TwrBsMyt (kN·m)
L_Ult		5.6E+3	5.6E+3	2.76E+4	2.76E+4	3.2E+5	3.2E+5
m	3					3.23E+7	3.89E+5
	8	1.67E+19	1.23E+18	3.03E+15	2.04E+14		
	10	2.53E+23	1.90E+22	1.03E+19	1.81E+17		

Table 2. Lifetime until failure (s) for various S/N curves (von Karman model – 50% TI)

		RootFxc1 (kN)	RootFyc1 (kN)	RootMxc1 (kN·m)	RootMyc1 (kN·m)	TwrBsMxt (kN·m)	TwrBsMyt (kN·m)
L_Ult		5.6E+3	5.6E+3	2.76E+4	2.76E+4	3.2E+5	3.2E+5
m	3					3.64E+6	2.65E+5
	8	1.05E+17	2.11E+17	4.55E+13	2.01E+12		
	10	6.20E+20	1.34E+21	4.86E+16	8.86E+14		

In Tables 1&2, the life until failure in seconds, for various S/N curves are shown. As it can be observed, there is no big difference in the values of the lifetime of the tower. The difference is in order of days or few months. However, the difference for the lifetime of the blade is significant. The change of turbulence from 1% to 50% reduces the time until failure in order of years; for the blade, the reduction is in 0.01 order of magnitude. The same procedure was made for the Kaimal spectral model. Very close results to that of the von Karman simulations appeared. In order to compare between both models' results, the time until failure results for the 01% turbulence intensity will be shown below.

Table 3. Lifetime until failure (s) for various S/N curves (Kaimal model – 01% TI)

		RootFxc1 (kN)	RootFyc1 (kN)	RootMxc1 (kN·m)	RootMyc1 (kN·m)	TwrBsMxt (kN·m)	TwrBsMyt (kN·m)
L_Ult		5.6E+3	5.6E+3	2.76E+4	2.76E+4	3.2E+5	3.2E+5
m	3					3.26E+7	3.85E+5
	8	1.67E+19	1.23E+18	3.07E+15	2.04E+14		
	10	2.53E+23	1.90E+22	1.06E+19	1.81E+17		

Comparing Table 3 to Table 2, the differences between the two models' lifetime until failure results are trivial. This indicates that both spectral models are effective in simulating the turbulent flow around the wind turbine.

4. CONCLUSIONS

From the discussed analyses, we can deduce that the turbulence intensity affects the fatigue behavior of the wind turbine significantly. The main trend of that effect is negative; the bigger the turbulence value, the shorter the lifetime until failure. This factor should be considered while designing the structure of a wind turbine, especially in areas subject to wind gusts or typhoons. The two spectral models used for simulation gave very close results. Both models showed the same behavior with increasing the turbulence intensities. Trivial errors between the two models' results occurred. And this includes that any of the two models can be used for simulating wind field around a wind turbine.

5. REFERENCES

[1] Fthenakis, V., and Kim, H. C., Land use and electricity generation: A life-cycle analysis, Renewable and Sustainable Energy Reviews 13 (2009) 6-7.

[2] Wind Measurement International website: http://www.windmeasurementinternational.com/wind-turbines/om-turbines.php

[3] Tony Burton, Nick Jenkins, David Sharpe, and Ervin Bossanyi, Wind Energy Handbook, 2nd Edition, John Wiley & Sons, UK, 2011.

[4] James F. Manwell, Jon G. McGowan, and Anthony L. Rogers, Wind Energy Explained: Theory, Design and Application, 2nd Edition, John Wiley & Sons, UK, 2009.

[5] Petersen, E.L., Mortensen, N.G., Landberg, L., Højstrup, J., and Frank, H.P., Wind power meteorology, Part I: Climate and turbulence, Wind Energy (1998).

[6] B.J. Jonkman, and L. Kilcher, TurbSim User's Guide: Version 1.06.00, NREL/TP (2012).

[7] Dayton A. Griffin, WindPACT Turbine Design Scaling Studies Technical Area 1 Composite Blades for 80- to 120-Meter Rotor, NREL (2001).

[8] D.J. Malcolm, and A.C. Hansen, WindPACT Turbine Rotor: Design Study, NREL/SR (2002).

[9] Shigley, J. E., Mischke, C. R., and Budynas, R. G., Mechanical Engineering Design, 7th Edition, McGraw Hill Higher Education, 2003.