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Study on extreme turbulence wind conditions of multibody dynamics simulation for MW-class wind turbine

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Abstract. Parametric modeling of NREL 5MW wind turbine was set up for multi-body dynamics simulation by the TurbSim, AeroDyn, FAST (fatigue, aerodynamics, structures, and turbulence) software respectively. According to the analysis of the characteristics of wind in the space discrete point, using TurbSim to establish the steady-state wind and random changes with time and space wind. Based on the AeroDyn software, which can coupled to FAST, we calculated the aerodynamic load. Loading the aerodynamic data which has been calculated, FAST can establish a fully parameterized simulation model. Making a comparison of the results obtained by FAST in 3 different wind conditions, the different of dynamic responses of the structure were obtained. The results obtained by FAST have some meaning in the study of wind turbine under extreme turbulence wind conditions.

1. Introduction
In order to obtain the accurate aerodynamic and structural loads changing over time of a wind turbine, it is important and necessary to input the natural wind which random changes with time and space. Such effects are mainly including the turbulence, wind shear, the tower effects, and so on. In wind power generation technology research phase, wind tunnel tests and experiments are reliable way. But it’s obviously not realistic and not economic. For a long time, many experts at home and abroad give input on modelling the wind farm. Varied wind spectral models have been obtained in different starting points [1-2].

Based on the above literature research, we used TurbSim as the wind simulator, AeroDyn as the aerodynamic simulator, By analysing the actual change of wind, it set 3 kinds of wind to model the NREL 5MW wind turbine’s dynamic response.

2. Wind Model
2.1. Spectral Model
TurbSim applied the power spectrum density function to measure the regular pulse pattern of wind in a short period of time. It used a modified version of the Sandia method [3] to create time series on account of spectral representation. We chose IEC Kaimal model as the spectral model.

IEC 61400-1 2nd ed. [4], and 3rd ed. [5] defines The IEC Kaimal model and assumes neutral atmospheric stability. The spectra for the three wind components, \( K = u, v, w \), are given by
where $f$ is the cyclic frequency and $L_K$ is an integral scale parameter. The IEC 61400-1 standard defines the integral scale parameter to be

$$L_K = \begin{cases} 8.10 \Lambda_u, & K = u \\ 2.70 \Lambda_u, & K = v \\ 0.66 \Lambda_u, & K = w \end{cases}$$

(2)

where the turbulence scale parameter, $\Lambda_u$, is

$$\Lambda_u = \begin{cases} 0.7 \cdot \min(30m, \text{Hub}Ht), & \text{Edition 2} \\ 0.7 \cdot \min(60m, \text{Hub}Ht), & \text{Edition 3} \end{cases}$$

(Note that the function $\min(x_1, x_2)$ in equation (3) indicates the minimum of $x_1$ and $x_2$.)

The relationships between the standard deviations are defined to be

$$\sigma_v = 0.8\sigma_u$$
$$\sigma_w = 0.5\sigma_u$$

(4)

2.2. Grid

We set a $21 \times 21$ grid to model the full-field wind change. Every point means a wind point which changes over time. Figure 1 shows the location of rotor points. The circle pictured here is the rotor diameter assumed for intuition.

The wind profile type: Power-law profile on the rotor disk; logarithmic profile elsewhere.

3. Dynamic Simulation Modeling

AeroDyn [6] is an aerodynamics software library (module) for use by designers of horizontal-axis wind turbines. It is written to be interfaced with a number of dynamics analysis software packages (such as FAST, ADAMS, SIMPACK, and FEDEM) for aero-elastic analysis of wind turbine models. Generalized Dynamic Wake (GDW) inflow model was used to calculate the induction factor; Beddoes-Leishman dynamic stall model was used to model the unsteady airfoil characteristics; Prandtl correction model was used in hub-loss and tip-loss. Figure 2 shows the flow how to model the dynamic simulation.

"Figure 1. The grid chart of the turbulent wind."

"Figure 2. The input and output file."
FAST (fatigue, aerodynamics, structures, and turbulence) [7] is developed by NREL as a streamlined CAE tool for prediction of wind-turbine loads and responses. The FAST Code is a comprehensive aeroelastic simulator capable of predicting both the extreme and fatigue loads of wind turbines. Meanwhile, FAST can compile and Link ADAMS and MATLAB.

4. Dynamic responses

4.1. The NREL 5MW wind turbine
The wind turbine used is developed by NREL (National Renewable Energy Laboratory). Most of the data used in simulation originates from the prototype developed by Repower Company. It can be widely used in onshore and offshore (shallow sea or deep water). The additional gross properties we chose for the NREL 5-MW baseline wind turbine [8], most of which are identical to those of Repower 5M, are given in Table 1.

| parameter           | description       | parameter         | description |
|---------------------|-------------------|-------------------|-------------|
| Rating              | 5MW               | Hub Diameter      | 3m          |
| Rotor Orientation   | Upwind            | Hub Height        | 90m         |
| Configuration       | 3 Blades          | Cut-In Wind Speed | 3m/s        |
| Control             | Variable Speed,   | Rated Wind Speed  | 11.4m/s     |
|                     | Collective Pitch  | Cut-Out Wind Speed| 25m/s       |
| Rotor               | 126m              |                   |             |

4.2. Simulation result
Blades are the main flexible components. Under the condition of large deflection, the tip of the blades may bump the tower, which cause destructive accidents. So we monitored the blades’ tip deflection. First, it calculated the wind turbine’s loads under the steady wind. Certain loading state of the blade 1 can be seen in Figure 3. The wind is 14m/s (longitudinal wind speed is 14m/s; lateral and vertical wind speed is 0m/s). Where OoPDefl1 means Blade 1 Out-of-Plane Tip deflection; IPDefl1 means Blade 1 In-Plane tip deflection.

![Figure 3. Blade 1 tip’s deformations under steady wind.](image-url)
It can be seen that OoPDefl deformations is distinct from IPDel under steady wind. At the beginning of the simulation OoPDefl has tremendous change, which can highly reach 5m. With the simulation going on, the fluctuation tends to a period. The OoPDefl fluctuation stables at 3m~3.3m, while the IPDel fluctuation stables at -0.2m~1.2m.

Next, it calculated the wind turbine’s loads under the unsteady wind. Certain loading state of the blade 1 can be seen in Figure 4. The reference wind speed at hub height is 14m/s (longitudinal wind speed is $U$; lateral wind speed is $V$ and vertical wind speed is $W$).

![Wind speed](image1)

![OoPDefl1](image2)

![IPDefl1](image3)

**Figure 4.** Blade 1 tap’s deformations under unsteady wind.

It can be seen that the deformations is distinct from steady wind. There is no discipline or period in the fluctuation which is more close to the natural wind conditions. The OoPDefl fluctuates ranging from -1m~7m, while the IPDefl fluctuation stables at -0.2m~0m.

At last, it calculated the wind turbine’s loads under the extreme unsteady wind. Certain loading state of the blade 1 can be seen in Figure 5. The reference wind speed at hub height is 24m/s, longitudinal wind speed is $U$; lateral wind speed is $V$ and vertical wind speed is $W$, while the Cut-Out wind speed is 25m/s.
Under the condition of extreme speed wind, it can be seen that at the beginning of the simulation OoPDefl has tremendous change, which can highly to -3m~5m. With the simulation going on, the fluctuation tends to decrease, and almost below 3m. It stables at the range of -3m~3m. The average OoPDefl is above 0m, while the IPDel changes at the range of -2.2m~1.8m.

By comparison, there are substantial differences in OoPDefl and IPDel under steady and unsteady wind speed. But the range of IPDel is always smaller than OoPDefl. Under the condition of extreme wind speed, the average of OoPDefl and IPDel are close to 0m.

Figure 6 shows the Rotor Torque when wind turbine is under 3wind conditions. At the beginning of the simulation under the steady condition, the Rotor Torque can reach highly as $6.59 \times 10^3$ kN·m. With the time going on, it remain stable at $4.18 \times 10^3$ kN·m. Under the unsteady 14m/s, the Rotor Torque is small at the beginning time. And it changes at the range of $3.78 \times 10^3$ kN·m~$4.51 \times 10^3$ kN·m. Under the extreme 24m/s, the Rotor Torque wildly fluctuates at the beginning of the simulation. It can reach highly as $7.65 \times 10^3$ kN·m. And then it changes at the range of $3.53 \times 10^3$ kN·m~$4.98 \times 10^3$ kN·m. Though the changing range is so close under the unsteady condition, the extreme wind fluctuates more frequently and wildly.
Figure 6. Rotor Torque under different wind speed

By comparing Rotor Torque under steady wind and unsteady wind, unsteady rated wind speed and Cut-out wind speed, it is not hard to find the different variation tendency. Under the rated wind speed, wind speed in all simulation area is constant, so the Rotor Torque steady at 4.18×10^3 kN·m. While the wind is unsteady, the Rotor Torque changes with the wind. When it high to Cut-out wind speed, the turbine control is Normal Pitch-to-Feather Shutdown. The fluctuation are more frequency and intense. Short time change can be as high as 1.5×10^3 kN·m, but the mean is the same as the steady condition. The reason for this is under the high wind speed the Rotor Torque is large, which the restoring torque is also big. If severe turbulent occurs in the wind and wind direction changes sharp, larger wind load and under the condition of large restoring torque make the Rotor Torque severe change.

5. Conclusion

It discussed how to simulate a wind field steady and unsteady, also how to establish the full dynamic model of wind turbine system by AeroDyn and FAST. Various simulations were conducted on the NREL 5MW wind turbine to investigate the dynamic response under 3 different wind conditions. The models of turbulence wind field established can be used as CAD/CAE program to confirm the aerodynamic analysis in extreme loads and fatigue loads of wind turbine.

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