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A new approach in fatigue analysis for onshore wind turbine

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1 Introduction

With the increasing size of wind turbines, the demand for reliable mechanical performance and lifetime design are increasingly important. Due to stochastic wind loads, the random cyclic loads acting on wind turbine towers may cause unexpected fatigue damages and thus reduce the operational lifetime of the wind turbine. However, the classical fatigue life prediction procedure is deterministic and cannot consider the random nature of the wind speed. Therefore, it is impractical to evaluate the local fatigue damage induced by the fluids from different orientations during the lifetime. Furthermore, the classical fatigue damage procedure cannot lead to the identification of the probability distribution of the fatigue damage due to uncertain wind speed. To address these shortcomings, a probabilistic approach is proposed in the present work to deal with wind speed in the evaluation of the fatigue damage of the wind turbine tower.

2 Proposed methodology

The NREL 5-MW baseline wind turbine is used in this work [1]. This reference wind turbine, originally designed to study in an offshore environment, is modified to be onshore. The boundary condition is considered as all DOF (degree of freedom) is zero on the ground level. The yaw angle control system is not implemented since it rarely contributes to fatigue damage in aeroelastic simulation.

The fatigue damage over the tower during the production phase is of great concern to the present research. Therefore, the wind condition with normal turbulence model (i.e. DLC1.1 defined in IEC61400-1:2005 standard) is used in simulation in which the mean wind speed at hub height is fixed between cut-in and cut-out speed to avoid the undesired influence of start-up phase and shutdown phase of the wind turbine. The mean wind speed changes linearly with steps of 2 m/s.

The IEC standard also recommends that at least a 60-min simulation or six 10-min simulations should be evaluated to consider the variance of turbulence. To find the appropriate number of simulation for onshore study, the simulation length is fixed to 10 minutes but each case of wind speed is simulated for 10 000 times. At each sample, the wind speed is changed aleatory in each simulation so that the variance of turbulence is taken into account.

2.1 Fatigue analysis

The wind turbine tower is modeled as a thin-walled cylinder structure by using beam finite element. The stress is evaluated at different heights of the tower. Several nodes, also called "tower gage", in the beam element are chosen to export the finite elements results (i.e. deformation $U(t)$, forces $F(t)$ and moments $M(t)$). These nodes will also be used to calculate the local stress at each level.

Since the shear stress is much less relevant to the fatigue damage than the axial stress [2], the nominal stress is the only component used in this fatigue analysis. The nominal stress across the section of the

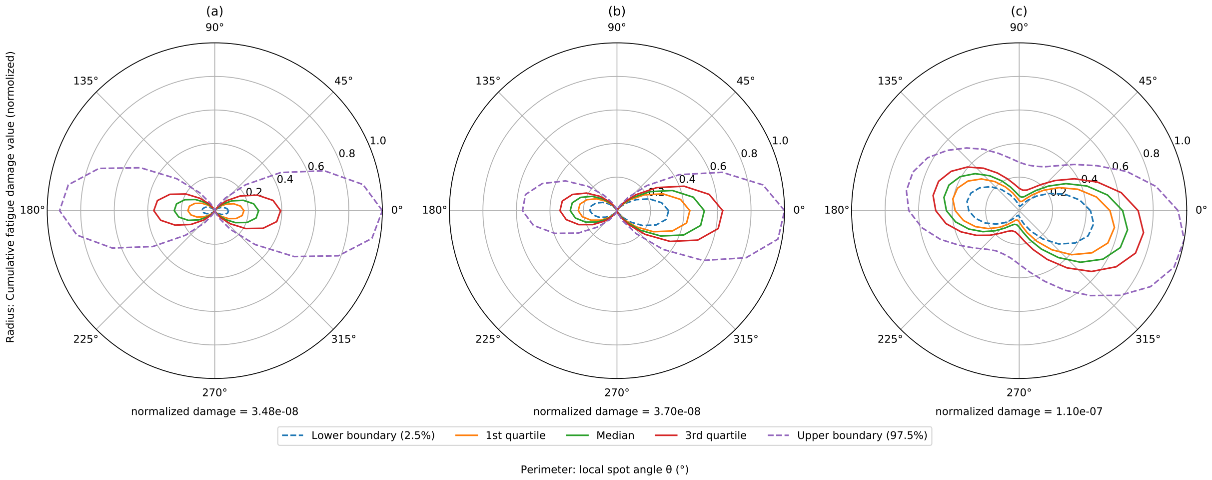

Figure 1: Distribution of fatigue damage at mean wind speed of (a)3m/s, (b)11m/s and (c)25 m/s

tower is calculated at different local spots along its circumference by Equation 1.

$$\sigma_{nominal}(t,z,\theta) = \frac{F_z(t)}{A(z)} - \frac{M_x(t)}{I_{Gx}(z)}R(z)\sin\theta + \frac{M_y(t)}{I_{Gy}(z)}R(z)\cos\theta \tag{1}$$

The stress state is evaluated over each local spot on every tower gage. Each local spot has a stress time history to evaluate the fatigue damage generated by wind at a given height of the tower. To calculate high cycle fatigue damage under uni-axial load, the S-N curve with Goodman correction is used. The cumulative fatigue damage is evaluated by Palmgren-Miner's rule while the original stress time history is extracted into cycles by the Rainflow counting method.

2.2 Probabilistic procedure

To deal with uncertain wind speed, Monte Carlo simulations are used where the deterministic procedure is performed at each mean wind speed for 10 000 times. For each sample the load-time history is calculated by FAST (Fatigue, Aerodynamics, Structures and Turbulence) Code, an aeroelastic simulator developed by NREL [3]. The fatigue damage is estimated by the fatigue analysis procedure described above. From these 10 000 simulations of the fatigue damage, the most appropriate probability distribution of the fatigue damage under a given wind speed is chosen by using the Kolmogorov-Smirnov test.

3 Result and conclusion

The distribution of the fatigue damage due to a unique in-coming direction of wind is illustrated in Figure 1. A form of "peanut" can be observed in all wind speed. Besides, the eccentric of distribution follows the downwind direction of the induced wind. The fatigue damage spreads out along in the downwind side. By fitting numerous probability distributions, the appropriate probability distribution that gives the best goodness of fit in all wind speed is also found.

Under stochastic wind conditions with mean speed between cut-in and cut-out speed, the present approach offers a way to get the probability distribution of cumulative fatigue damage on the cross-section at different heights of the tower. This can be used to investigate the reliability of wind turbine considering the cumulative fatigue induced by the wind from different directions.

References

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