博士論文（要約）

A Study of Extreme and Fatigue Loads on Wind Turbines during Power Production

（風車発電時の最大風荷重と疲労荷重に関する研究）

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Extreme and fatigue loads during operation are important load cases for the design of wind turbines. Current international design standard require wind turbines to be designed for extreme load during power production for a 50 year return period, which is derived from statistical extrapolation of limited amount of numerical simulations. This approach however gives large uncertainty and a simplified approach is needed for site assessment of wind turbines. Fatigue load is also to be calculated for 20 years at given site conditions, this is also impractical for site assessment and a simplified model is needed.

Several studies have been carried out on dynamic investigation of the characteristic of extreme and fatigue loading during operation. However, most of them are based only on numerical simulations with little validation or are only applicable to limited parts of the wind turbine, i.e. tower base.

In this study, firstly, a wind turbine model which is able to represent real wind turbine response and clarify the sensitivity of some control parameters on extreme and fatigue load is developed, and the model is validated with measurement data from the 2.4MW Choshi Wind Turbine. Secondly, an empirical model of extreme load estimation applicable to all heights of the tower is proposed. Thirdly a simplified empirical model of fatigue load estimation is proposed.

Chapter 1 is an introduction containing the general background of the research. Reviews of existing studies and the research objectives of this study are also presented.

In Chapter 2 the measurement data of Choshi 2.4MW Wind Turbine is described. The bending moments of the tower at three different heights of the wind turbine are measured by using strain gauges. SCADA data from the wind turbine is used so that only the data during operation is analyzed. By taking bin average of the tower base moment for each wind speed bin, the characteristics of the maximum tower

moment in fore-aft direction is made clear. At the tower top, the loads are dominated by the cut-out wind speed, while at the tower base it is more dominated by the rated wind speed.

In Chapter 3 the wind turbine model is developed and the validation of the dynamic simulation is carried out. The tower of the wind turbine is modelled by using detailed tower specifications from the manufacturer. The data from the manufacturer are also used to model the center of gravity and weight of the nacelle, blades and hub, and the twist angle of the blades. The aerodynamic characteristics of the blades are modelled based on standard airfoils and the control algorithm is modelled based on the JSCE guideline. Then dynamic simulation is carried out and validated by measurements. The sensitivity of the response to different control parameters and wind models is also investigated. It is found that by applying gain scheduling in the control algorithm, the overestimation in higher wind speeds region is improved. Two different wind turbulence models are also compared, it is concluded that the structural response is better predicted by using the Mann's model rather than the Kaimal's model. Then the equivalent fatigue load and the load probability distribution for both the measurement and numerical simulation are calculated and it was found that the simulation is able to give good agreement with measurement.

In Chapter 4, a simplified empirical model for extreme load estimation is proposed. For the estimation of the mean of the maximum tower bending moment, a new model is proposed in which the rotor moment is considered in addition to the thrust force on the rotor. The proposed model shows good agreement with full simulation and measurements, not only at the tower base but also at the tower top. For the statistical extrapolation of extreme load, firstly a new convergence criterion is proposed for load extrapolation by limiting the relative error between the original data and the fitted distribution. By using this method, the coefficient of variation of the extreme 50 years load is reduced significantly. Then a new approach is proposed in which the ratio of the 50 year maximum moment and the mean of the maximum moment is defined by subtracting the mean value. In the conventional approach, the ratio is a function of turbulence intensity, position in the tower and annual mean wind speed. However, by using the proposed approach a unique value can be used for any turbulence intensity, position in the tower and annual mean wind speed.

In Chapter 5 a simplified empirical model for fatigue load estimation is proposed. The fatigue loads on the wind turbine tower are investigated for different turbulence intensities, annual wind speed, shape factor of the Weibull distribution of the annual wind speed, and the power exponent of the vertical wind speed profile. Fatigue load changes most significantly with turbulence intensity and only slightly with different annual wind speed and shape factor of the probability distribution; while wind shear has virtually no effect on fatigue load. Unlike extreme load, the difference of fatigue load is the same for all heights of the tower. This is because fatigue is dominated by the fluctuating component of the response, which does not differ from the base to the top. Then an empirical model of fatigue load estimation is proposed.

In Chapter 6 the conclusion containing the summary of the results of the study and future research plans are presented.