

学 位 論 文 の 要 旨

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学位論文題 Load and Power Control of Horizontal Axis Wind Turbine 英訳又は和訳 (水平軸風車の荷重と出力の制御)				
<p>The operating condition of Horizontal Axis Wind Turbine (HAWT) is extremely complex in natural wind condition. Therefore, considering effect of complex wind conditions on load and performance and suggesting the control method to decrease load of the HAWT are necessities. One of the control methods is a cyclic pitch control. The objective of this thesis evaluated load and performance of HAWT under turbulence wind, gust wind and the diagonal inflow wind conditions.</p> <p>In chapter 1, firstly, the historical development of wind energy in the world and Japan are introduced concisely. Next, the wind turbine technology is presented. It can be divided into two main types: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The HAWT is reclassified into upwind and downwind wind turbines. And then, previous studies of Floating Horizontal Axis Wind Turbine and the research purpose are represented.</p> <p>In chapter 2, the main nomenclatures in this thesis are shown.</p> <p>In chapter 3, wind turbine control method and loads of wind turbine are reviewed. Further, FAST (Fatigue, Aerodynamics, Structures and Turbulence) code also was described. The FAST code is a nonlinear time-domain simulation tool that is capable of modeling the coupled aero-hydro-servo-elastic response of onshore and offshore systems.</p> <p>In chapter 4, the experiment of turbulence wind was exhibited. The experimental data was compared with QBlade software based on Blade Element Momentum Theory. The performance of the blade used Avistar airfoil shape was tested in low Re number region ($Re = 0.5 \times 10^5$, 1.0×10^5, 1.5×10^5 and 2.0×10^5). The experimental results shown that the blade performance is stable when the low Re number changed. The turbulence level has significant impacts on wind turbine performance because the increased transport of momentum from the free-stream to the blade surface increases the streamwise momentum in the boundary layer. This allows the flow to overcome the pressure gradient of the blade surface, so the separation region is much shorter and the performance is larger.</p> <p>In chapter 5, the aerodynamic forces acting on a small HAWT under extreme wind direction change condition in the wind tunnel experiments was evaluated. This study is intended to clarify the load fluctuation when sudden wind direction change reacts to two-bladed and three-bladed wind turbines. A vane system is used to generate the wind direction change.</p>				

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The optimal tip speed ratio ($\lambda = 7.15$) of two-blade wind turbine is higher than the optimal tip speed ratio ($\lambda = 5.62$) of three-bladed one. The yaw moment of the two-bladed shows larger fluctuation than the three-bladed one. The average yaw moment fluctuation amplitude of two-bladed wind turbine is about 39% larger than the three-bladed one. The fluctuation time of three-blade wind turbine is shorter than the two-bladed one. This proves that the three-bladed wind turbine has higher solidity. The pitch moment fluctuation amplitude of the two-bladed wind turbine has two peaks at the azimuth angles of $\phi_{WDC} = 60^\circ$ and 200° .

In chapter 6, the experimental results and discussion of the cyclic pitch control are shown. For the front inflow wind condition, the power coefficient and thrust coefficient were measured when changing the pitch angle θ from -2° to 2° at the mainstream wind velocity $U = 10\text{m/s}$ and the optimum tip speed ratio $\lambda = 7.4$. The results showed that the maximum power coefficient decreases when the pitch angle increases or decreases from $\theta = 0^\circ$. The optimum value of the pitch angle is $\theta = 0^\circ$ and the maximum power coefficient is $C_P = 0.405$.

In this experiment, for the diagonal inflow wind condition, the yaw angle is set to $\varphi = -5^\circ, 0^\circ, +5^\circ$ and the pitch angle amplitude is controlled at $-1^\circ \leq a \leq 1^\circ$. The power coefficient slightly increases as the pitch angle amplitude a increases. The pitch angle amplitude a indicates the maximum power coefficient variation depending on each phase angle of ξ . At the pitch angle phases of $\xi = 30^\circ, 60^\circ, 120^\circ$ and 150° , the pitching moment coefficient C_{Mx} and the yaw moment coefficient C_{Mz} linearly change with respect to the pitch angle amplitude a . This can prove that it is possible to control the magnitude of the moment acting on the rotor surface by adjusting the pitch angle amplitude of the periodic pitch change in the oblique inflow wind condition. Compared with a point of the moment coefficient of the optimum operating condition in the front inflow wind condition, it equals the average value of the aerodynamic load acting on the rotor face in the diagonal inflow wind condition at the pitch angle phase of $\xi = 60^\circ$. Therefore, the cyclic pitch control method is possible to reduce the aerodynamic load acting on the rotor surface during one rotation.

In chapter 7, the experimental conditions were simulated by FAST code in the steady pitch control and the cyclic pitch control. For the power and thrust coefficient simulation, in the low tip speed ratio and high tip speed ratio regions, there are differences between simulation results and experimental data because the simulation is not possible to fully take into account the flow field caused by the separated flow on the blade surface. However, around the optimum tip speed ratio, the simulation results is in good agreement with the experimental values. For the pitching moment and yaw moment, the simulation results are the same trend with experimental data.

In chapter 8, the conclusion of this research is described in the thesis.