An Innovative Umbrella-Type Rotor of Horizontal Axis Wind Turbine to Regulate Power and Reduce Wind Thrust

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Introduction

The development of wind turbine is consistently associated with two topics, the power regulation and wind loads reduction. Power regulation is typically achieved by blade stall and pitch control. New approaches have been proposed, for example the retractable rotor [1] and blade partial span pitch control [2]. For wind loads reduction, the DOWEC project proposed a pre-coned upwind rotor with flexible blades [3]. Segmented ultralight pre-aligned rotor has also been raised [4].

In current study, an innovative umbrella-type rotor is proposed. This rotor aims to offer a new approach to regulate power and reduce wind thrust. The rotor is upwind configured and allows blade to fold upstream at hub according to wind conditions, which resembles the umbrella configuration. The folding axis, however, is not perpendicular to the blade span, and instead, inclines to it, tilting down to the rotor revolution direction. Consequently, the rotor is pitching and coning coupled by the folding hinge structurally and the folding axis incline angle (γ) determines pitching and coning sensitivities. The proposed rotor is illustrated in Fig. 1. Rotor pitching results in power regulation and wind thrust reduction, and the coning results in swept area reduction which offers extra capability in lowering wind thrust. The patent authorization of this rotor concept and corresponding hub design is in process [5]. Current study focuses on the umbrella-type rotor performance in power regulation and wind thrust reduction by wind tunnel experiment with rotor models. The folding mechanism will be studied in the future researches.

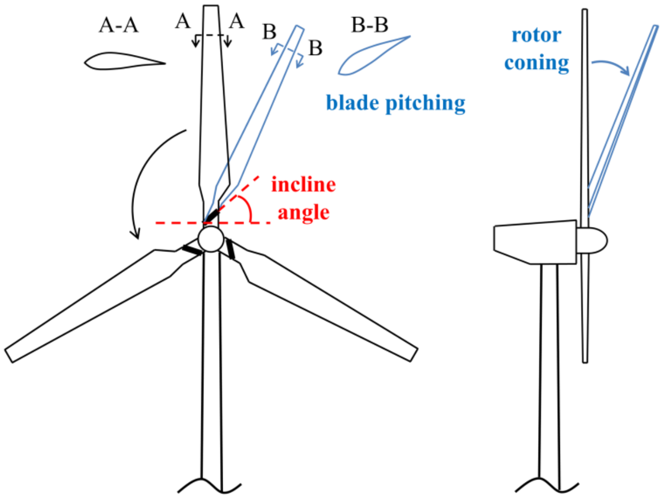

Fig. 1 Concept of innovative umbrella-type rotor

Approach

The experiments were conducted in a low speed wind tunnel in Tsinghua University. A rotor test system with a magnetic brake and sensors to measure revolution rate, torque and wind thrust was set up, shown in Fig. 2. The tested rotors have a diameter of 0.65 meter with a blockage ratio of 14.7% and are configured with three blades. The blades were modified from “NREL Phase VI” blades with a length of 0.3 meter. The original blade test conditions were not available in current experiment due to facility capacities including load and revolution rate limit. Besides, in the trial test, the power of rotor with 0.3 meter scaled down original blades was found to increase initially during pitching process. As the innovative rotor is for active power regulation, the blade should reduce power output consistently during pitching process. Thus the tested blade was pre-pitched with 20°. The modified blade also possesses a much lower Cp (power coefficient) and TSR (tip speed ratio), meeting the facility requirements. Since the experiment is to prove the innovative rotor validity, this modification is believed to be reasonable. Three hubs with incline angle of 30°, 45° and 60°, a pitch regulated hub and blades were 3D printed with synthetic resin. The blades were fixed at desired fold or pitch angle manually in the experiments. Tested rotors are shown in Fig. 3. The wind thrust data was collected for the whole turbine including rotor and nacelle, and then the turbine Ct (thrust coefficient) was calculated. Rotor swept area diminishment due to rotor coning was not taken into account in data analysis. The blockage correction was considered based on ref. [6].

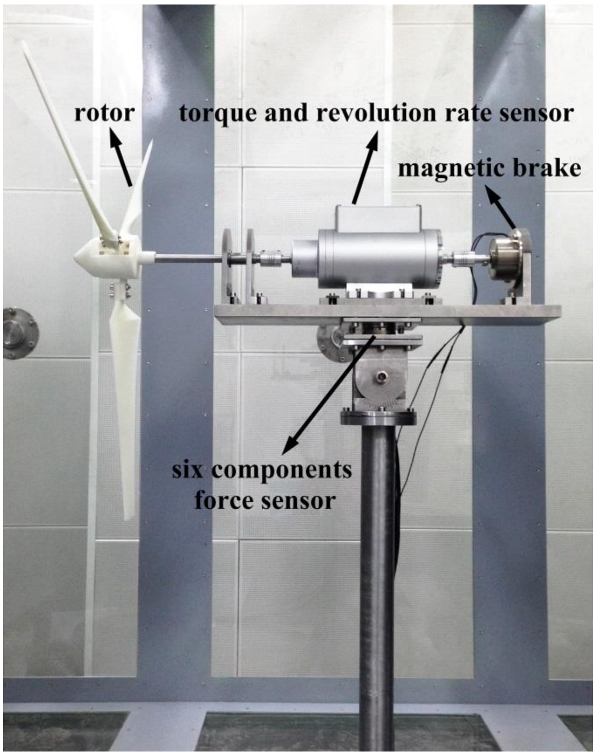

Fig. 2 Photograph of rotor test system

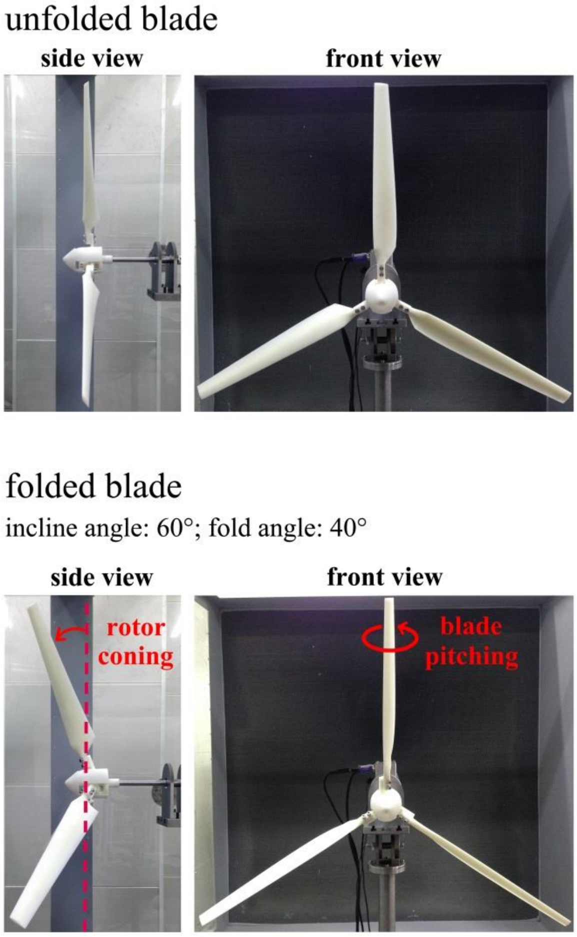

Fig. 3 Photograph of tested umbrella-type rotor

Firstly, turbine Cp and Ct were measured in wind speed of 4 m/s for rotor with γ of 45°. This experiment is to study the innovative rotor aerodynamic performance. Then, in higher wind speed, the rotors were folded or pitched to regulate power. This experiment was conducted for rotors with γ of 30°, 45° and 60° and pitch regulated rotor. Finally, based on power regulation experiment data, Cp regulation sensitivity was analyzed for three umbrella-type rotors. Wind thrust was compared between turbines with umbrella-type and pitch regulated rotors, and Ct regulation sensitivity was also analyzed.

Main body of abstract

The turbine Cp and Ct for rotor (γ=45°) in wind speed of 4 m/s are shown in Fig. 4. A drastic drop of both Cp and Ct, and a shift of TSR to lower range are found as the blade is folded. The turbine highest Cp and Ct are 0.048 and 0.28 respectively for normal rotor, while they drop to 0.009 and 0.16 for rotor with fold angle of 40°. This rotor behavior is favorable in high wind speed. The decline of Cp and Ct could lead to limitation on power and wind thrust growth, and low TSR avoids the over speed of rotor. The result shows that the innovative rotor has potential to achieve both power and wind thrust regulation.

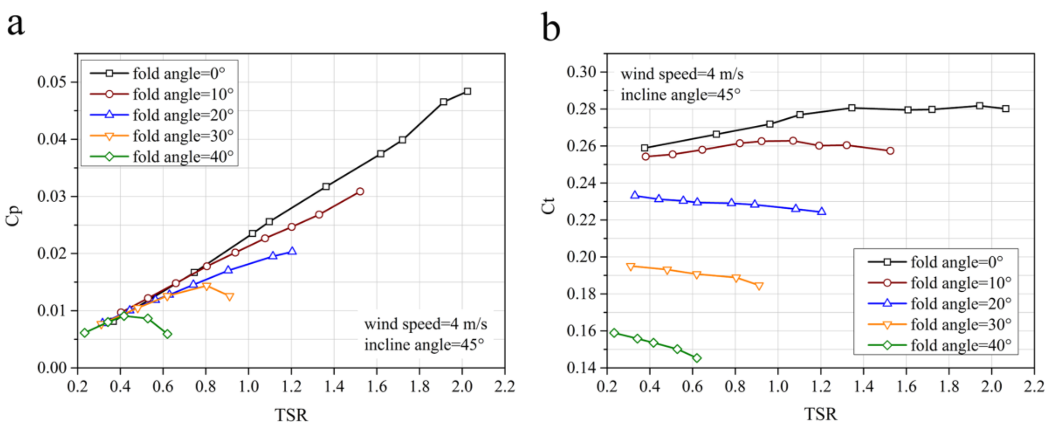

Fig. 4 Umbrella-type turbine performance: (a) Cp variation along TSR and (b) Ct variation along TSR

Fig. 5 shows the rotor fold angle variation along wind speed to maintain constant power of 0.521 watt. In the experiment, the brake torque was fixed and the rotor revolved at 200 rpm constantly. The wind speed was adjusted so that the rotor maintained the constant speed and power output. Results reveal that fold angle increases as the wind strengthens and the adjustment is less at larger incline angle. This result sufficiently demonstrates that the rotor is capable in regulating power and limiting speed growth in high wind speed.

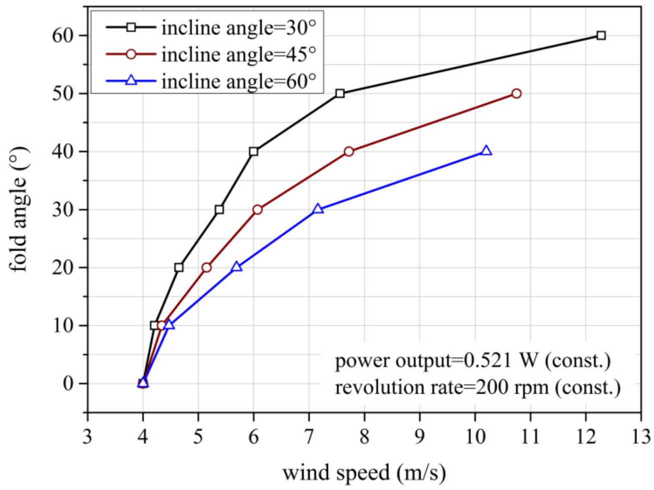

Fig. 5 Fold angle variation along wind speed to maintain constant power

Based on power regulation experiment data, rotor Cp variation along fold angle is analyzed shown in Fig. 6. For all tested rotors, Cp decreases with the increase of fold angle. It should be noticed that larger incline angle leads to more sensitive Cp regulation. At fold angle of 40°, Cp is 0.0024 for rotor with γ of 60°, which is simply 20.39% to that with γ of 30°. This is due to the fact that larger incline angle leads to higher pitching rate. The experiment result indicates that incline angle is the key to Cp regulation sensitivity.

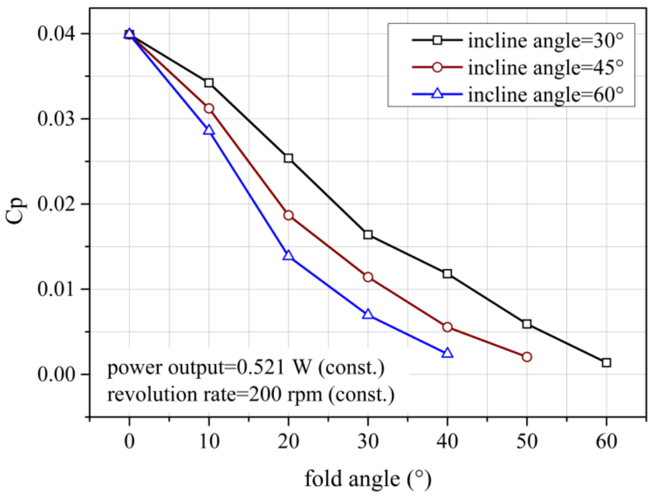

Fig. 6 Umbrella-type rotor Cp variation along fold angle

An identical power regulation experiment was conducted for the pitch regulated rotor. Wind thrust data for turbines with three umbrella-type and pitch regulated rotors are presented in Fig. 7. Under identical operating conditions, lower wind thrust is observed for umbrella-type turbines as compared to pitch regulated type. This phenomenon corresponds to the distinct rotor coning configuration which is not available for pitch regulated type. A detailed analysis on the thrust comparison is shown in Fig. 8. As can be seen, the smaller incline angle is, the less wind thrust the turbine bears. For turbine with γ of 60°, the highest thrust is 98.2% to that of pitch regulated type, yet it is 92.6% for turbine with γ of 30°. This is reasonable as smaller incline angle provides a lower pitching rate and a higher coning rate. The umbrella-type turbine Ct variation along fold angle is presented in Fig. 9. Similar to Cp, Ct declines considerably for all tested rotors and the variation is more sensitive at larger incline angle. Considering Fig. 6, Fig. 8 and Fig. 9, for umbrella-type rotor, blade pitching is the key to Cp and Ct regulation sensitivity, while under identical Cp conditions, rotor coning provides an extra capability in lowering Ct.

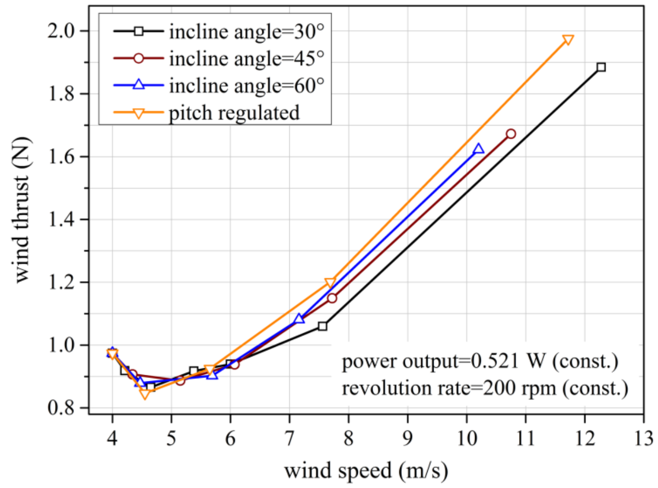

Fig. 7 Wind thrust variation along wind speed for tested turbines

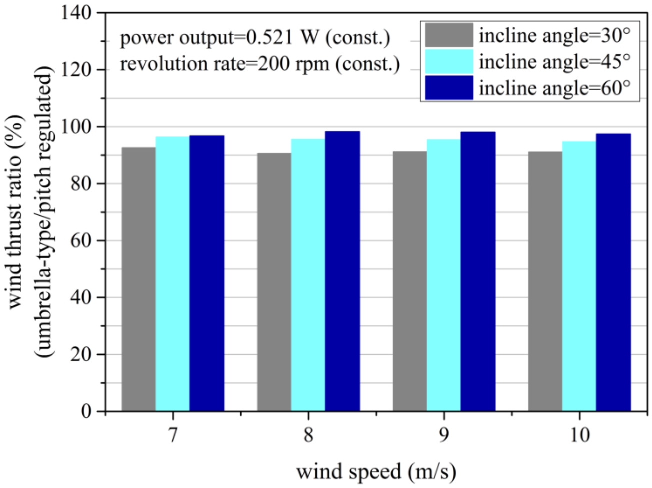

Fig. 8 Wind thrust ratio of umbrella-type to pitch regulated turbine

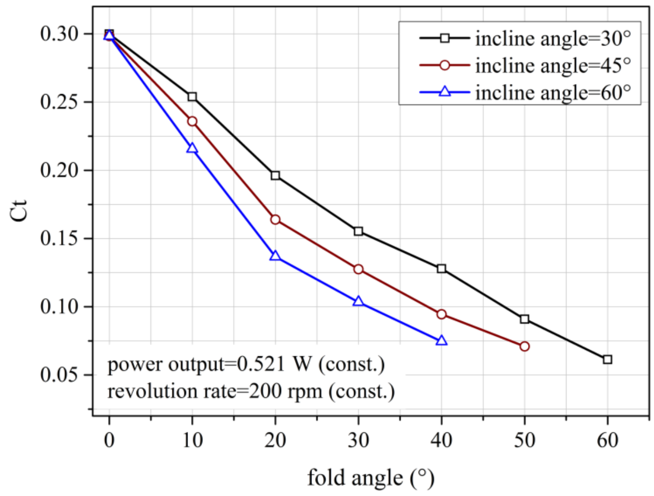

Fig. 9 Umbrella-type turbine Ct variation along fold angle

Conclusion

An innovative umbrella-type rotor concept for power regulation and wind thrust reduction is proposed. Rotor models were made and wind tunnel experiments were conducted. The turbine Cp and Ct declined considerably when the rotor was folded. Constant speed of 200 rpm and power of 0.521 watt were achieved with the umbrella-type rotor models in increasing wind speed. Innovative rotor is more desirable in lowering wind thrust than pitch regulated type, with the maximum reduction of 7.4% in current study. It is found that for innovative rotor, larger incline angle leads to both more sensitive Cp and Ct regulations.

This study is supported by the National Natural Science Foundation of China (No. 51575296).

Learning objectives

After participating in this presentation, the attendees will:

1. Hold a positive view of the distinct design of umbrella-type rotor with pitching and coning coupled feature.

2. Realize the innovative rotor excellent performance in power and wind thrust regulation.

3. Understand the rotor coning effect on lowering wind thrust.

Reference

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[6] Ryi J., Rhee W., Hwang U.C., Choi J-S. Blockage effect correction for a scaled wind turbine rotor by using wind tunnel test data. Renewable Energy 2015;79:227-35.