Study on the Performance of Vertical Axis Wind Turbine with Two Sets of Blades

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Abstract. This paper investigated the impact of added auxiliary blades on the performance of vertical axis wind turbine through adjusting blade spacing and blade pitch angle by means of experimentation. The results show that a critical value of blade spacing affects the performance of turbine, and with the decrease of blade spacing, the output power coefficient of the turbine decreases but the automatic startup performance increases when under low tip speed ratio. In addition, the output power of pitch angle $\beta$ was the largest when it was 3°, which increased by 3.9% compared with that of 0°. The power of pitch angle $\beta$ was relatively close in the range of -3° ~5°.

1. Introduction
At present, the wind turbines which are generally installed on the shoal near the shore are difficult to make full use of offshore wind energy. Single-layer wind turbine has low power generation efficiency, high failure rate and small application range. Single-layer horizontal axis wind generator cannot meet this special environment [1].

Wind turbine can be divided into horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) according to the direction of its rotation axis and airflow direction [2]. In the past nearly a century, through the continuous efforts of scholars, the theory of wind turbines has been constantly improved, from the initial windmill model to Bates theory to obtain the theoretical maximum efficiency [3]; From the improvement of the model of the horizontal axis wind turbine to the study of the distribution of air distribution in computational fluid dynamics, the field of wind power has developed very fully [4].

The main reason for the development of horizontal axis wind power generation devices at home and abroad in the early years is that the wind energy utilization rate is higher than that of vertical axis wind turbines, and the automatic-startup performance is obviously better [5], so it has been widely concerned and studied. At present, the research theory of horizontal axis wind turbine is rich [6]. After a lot of research and experiments, excellent blade profile and mature variable pitch technology have been obtained, which has high power generation efficiency and mature market commercialization [7]. But many shortcomings is not horizontal axis wind turbine with the deepening of the research and completely eliminate [8], horizontal axis due to the structure of the horizontal axis itself under the condition of the turbulent flow of power generation efficiency is very low, at the same time since the launch of horizontal axial turbine in order to optimize performance and output performance, design of leaf size and speed usually larger, caused by noise pollution, and its size limits its use of the environment [9]. In recent years, due to the vertical axis wind turbines with a small structure, easy installation, low noise and able to take advantage of the obvious advantages of turbulent wind, able to adapt to the special environmental requirements [10], the vertical axis wind turbine research gradually...
rise, still belongs to the early stage, the direction of the need to conquer mainly for how to improve the utilization rate of wind energy and increase since the start of the wind turbine performance [11].

Vertical axis wind turbine according to the structure of blade and the wind forces can be divided into different lift type vertical shaft type vertical axial wind turbine. Since the start of the wind power generator capacity is relatively good, able to start under low wind speed, tour of requirements is low, easy to install, but its low utilization rate of wind power, efficiency is generally lower than 20%, thus seriously restrict the development of resistance type wind turbine. Lift type wind turbine are more widely used, the main advantage is that the wind energy utilization rate is higher, after optimization of lift type vertical axis wind turbines have been able to exceed the single-layer horizontal axis wind turbine, the single-layer vertical shaft lift type wind power generator has two shortcomings: since the launch of instability and poor performance.

Taking h-type vertical shaft turbines as the research object, this paper compares the output performance and self-starting performance of double-layer blade turbines with that of single-layer single-layer blade turbines. The output power and starting torque of wind turbines with different structures can be obtained by changing the size of turbines and blade. It will provide some help for the future research and development of vertical shaft turbines with different structures.

2. Experimental Consideration

2.1. Laboratories and Wind Tunnels
In this paper, the number of blade layers, the distance between double-layer blades, and the pitch angle of blades are taken as variables to conduct experimental research. Data such as wind speed, wind turbine rotational speed, and output power of the wind turbine under different working conditions are recorded by experimental data acquisition equipment, and the results of different groups of experiments are compared and analyzed.

The wind tunnel is a self-built small wind tunnel, which is composed of an axial blower in the front section, a fairing in the middle section and a ventilation duct at the back end. The schematic diagram of the model is shown in figure 1.

![Figure 1. Schematic model of wind tunnel](image)

The basic size of the laboratory is 11.2 m * 9.3 m * 3.9 m, and the overall size of the wind tunnel is 8.22 m * 2.55 m * 2.55 m. The controlled wind speed of the turbine is 0 ~ 10.5 m/s, and its actual wind speed is 0 ~ 9.3 m/s. Four axial flow blowers are placed on the support at the front of the wind tunnel. The maximum diameter of the single blower is 790 mm, the maximum height is 1008 mm, the thickness is 550 mm, and the maximum weight is 60 kg. Fairing and grilles are installed in the middle of the wind tunnel to ensure a relatively stable flow field around the wind turbine, and the maximum wind speed within the fairing is 9.3 m/s. In order to make the flow field of the wind tunnel as stable as possible under the condition that the wind speed of the turbine is sufficient, it is required to withstand the maximum wind speed without excessive noise in the design. The side opening of the wind tunnel facilitates the change of turbine structure and placement of turbines. The tail opening is used to pull out the generator wiring and connect it to the output power test device. The wake flow of the wind tunnel flows out from the outlet to ensure that the airflow field at the outlet is the same as that at the far field. The rest of the whole structure adopts bracket and skin structure, the physical picture of the side of the wind tunnel is shown in figure 2.
2.2. Vertical Axis Wind Turbine

The vertical axis wind turbine is mainly composed of a square base at the bottom, a power generating rotor at the bottom, a rotating axis in the middle, a symmetrical crossbar at the top and bottom, it absorbs wind energy and converts it into kinetic energy through blades. The blades rotate for generating electricity from the rotor. The upper end is connected with the rotary shaft disc, which has a diameter of 8 cm and the diameter of the rotary shaft is 3.6 cm. The base of the turbine is placed at the bottom of the lower end, and the base leads to the wiring. Due to the small size and strong structural stability of the device, the thickness of the rotary shaft has a great impact on the aerodynamic performance of the wind turbine, so the finer shaft is selected. The physical drawing of power generation rotor is shown in figure 3.

![Figure 3. Physical picture of generator rotor](image)

The upper part of the wind turbine is equipped with symmetrical upper and lower crossbar, which can be used with a length of 57 cm. The outer side of the crossbar is connected with the outer blade through the pitch angle changing device, that is, the rotation radius of the outer blade is 0.57 m. The length of the outer blade is 0.55 m, while the inner blade is drilled in the middle of the upper and lower connecting rod according to the required rotation radius, and its length is 0.35 m. The farthest pin hole is 0.36 m away from the rotation center, and holes are drilled every 3 cm to change the blade spacing experiment. The physical drawing of the wind turbine is shown in figure 4.

![Figure 4. Physical picture of wind turbine](image)
Inside section of up and down bars is connected to the rotor disc, a total of three sets spaces between 120°, then install variable pitch device of rail lateral, the outer part of the pitch changing device is connected with the blade pin, and the inner part is connected with the crossbar with a single degree of freedom, and the rotation angle can be changed by -15° ~ 15°, variable pitch angle device model diagram as shown in figure 5.

![Figure 5. Variable pitch angle model and variable pitch angle object](image)

2.3. Measuring Device
The device for changing wind speed in the experiment is shown in figure 6 (a). The range of wind speed adjustment is 0-10 m/s. During the experiment, four frequency converters are simultaneously adjusted to ensure stable air supply. In this experiment, the output power coefficient of wind turbine is measured by a power meter, which is shown in figure 6 (b).

![Figure 6. The ignited lithium (a). Speed control system](image)  ![Figure 6. The ignited lithium (b). Wattmeter](image)

3. Results and Discussion
Based on the basic requirements of scientific experiments in repetitive experiments, this section uses the above devices and measurement methods to conduct repeated experiments on the output performance of double-layer blades in the laboratory environment for two consecutive times. Take the output performance and auto-startup performance experiments of single-blade turbine as example, the pitch angle $\beta = 0^\circ$ changes the output power coefficient of wind speed measurement under different wind speed, and wind turbine power output change with wind speed curve as shown in figure 7.
The figure above shows that the output power of the single-blade turbine is basically the same after two experiments under the same rotation radius, with an average error of less than 5%. At the same time of measuring the output power, a repetitive experiment of automatic-startup performance was carried out, and the minimum starting wind speed of two consecutive times in this condition was obtained, and the automatic-startup wind speed was almost identical. As mentioned above, the performance test of vertical axis wind turbine carried out by this experimental device has well repeatability.

The automatic-startup performance of turbines with different blade spacing was tested. Double-layer wind turbines with inner/outer blade rotation radius of 0.42 m/0.48 m, 0.39 m/0.51 m, 0.36 m/0.54 m, 0.33 m/0.57 m and single-layer turbines with \( r = 0.45 \) m (blade spacing of 0 m) were measured respectively, as is shown in figure 8.

The experimental results show that the automatic-startup wind speed of the single-blade turbine is basically the same as that of the double-layer turbine with larger blade spacing S. The minimum starting wind speed is 3.3 m/s. With the decrease of blade spacing S, the starting wind speed gradually decreases, reaching a minimum of 2.9 m/s.

Experiments were conducted on the output power of turbines with different blade spacing. Double-layer turbines with inner/outer blade rotation radius of 0.42 m/0.48 m, 0.39 m/0.51 m, 0.36 m/0.54 m,
0.33 m/0.57 m and single-layer turbines with \( r = 0.45 \) m (blade spacing of 0 m) were measured at different wind speeds. The output power of turbines with different sizes at different wind speeds was shown in figure 9.

![Figure 9](image_url)  
**Figure 9.** Measurement results of output power of wind turbines with different blade spacing

Experimental results show that the blade pitch \( S = 12 \) cm and the experimental results showed that the output power of the two groups of experiments with blade spacing \( S = 12 \) cm and \( S = 18 \) cm was basically the same. When \( S = 6 \) cm, the power decreases significantly, and the power of any double-blade turbine at different wind speeds is higher than that of the single-blade turbine, but it is not reflected in the fast attenuation of the output performance of the double-blade turbine at high velocity ratio. During the observation and experiment, the turbine rotation speed increased with the increase of wind speed, and the rotation speed remained basically unchanged after the wind speed reached 8 m/s. In the case of the turbine with the highest wind speed of 10.5 m/s, the tip speed ratio \( \lambda \approx 1.5 \).

The output power of turbine with different pitch angle \( \beta \) is measured. The double-layer turbine with blades in the range of pitch angle \( \beta = -15^\circ \sim 15^\circ \) is measured at different wind speeds. When the pitch angle \( \beta < -10^\circ \) or \( \beta > 10^\circ \), the experiment finds that the output power has decreased significantly. Therefore, the experimental data of seven groups of turbines with different pitch angles in the range of \(-10^\circ \sim 10^\circ \) are given here, the different pitch angle under different wind speed wind turbine power output as shown in figure 10.

![Figure 10](image_url)  
**Figure 10.** Measurement results of turbine output power with different pitch angle
The output power of several groups of turbine with different pitch angle is compared. Between -3° and 3°, the output power of the turbine is very close. After the wind speed is more than 7 m/s, when the pitch angle is 3°, the output power is gradually greater than that of β = 0° and β = -3°. In the wind speed between 3.5 m/s and 10.5 m/s, the output power of pitch angle β = -3° increased by 3.9% compared with that of β = 0°, and the power of pitch angle β = -3° was basically the same as that of β = 0°. Comparing the output power of positive pitch angle and negative pitch angle, the output power of positive pitch angle is obviously larger than that of negative pitch angle. When the pitch angle is between -3° and 5°, the output power is close. When the pitch angle changes more than this range, the power decreases rapidly.

4. Summary and Conclusion
In this paper, the single and double layer turbine with different sizes is tested by changing blade spacing and blade pitch angle. In the process of experiment, repeatability is verified to reduce the contingency.

According to the effect of blade spacing on performance, the output performance and automatic-startup performance were tested. When the blade spacing was S > 12 cm, the output power was basically equal. With the decrease of blade spacing, the output power decreased. In terms of automatic-startup performance, the automatic-startup performance increases with the decrease of blade spacing.

The influence of pitch angle on output performance was tested. In the case of turbines with experimental size, the output power of pitch angle β was the largest when it was -3°, which increased by 3.9% compared with that of 0°. The power of pitch angle β was relatively close in the range of -3°–5°.

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6. References
[1] Tescione G, Ferreira C J S and Van G J W. 2016 Analysis of a Free Vortex Wake Model for the Study of the Rotor and Near Wake Flow of a Vertical Axis Wind Turbine J. Renewable Energy 87(1): 552-563.
[2] Rezaeiha A, Kalkman I and Blocken B 2017 CFD simulation of a vertical axis wind turbine operating at a moderate tip speed ratio: Guidelines for minimum domain size and azimuthal increment J. Renewable Energy 107: 373-385.
[3] Ying Wang, Xiaojing Sun and Xiaohua Dong 2016 Numerical investigation on aerodynamic performance of a novel vertical axis wind turbine with adaptive blades J. Energy Conversion and Management 108: 275-286.
[4] Zhonghe Han, Peng An, Shufeng Zhang and Yalei Jia 2017 Aerodynamic performance of wind turbine with double blade type airfoil J. Renewable Energy Resources 35(10): 1523-1529.
[5] Chen Zhang 2017 The research on the key technology of horizontal axis wind power generation with concentrated wind D. Northeast Forestry University.
[6] Elkhoury M, Kiwata T and Aoun E. et al 2015 Experimental and numerical investigation of a three-dimensional vertical-axis wind turbine with variable-pitch J. Journal of Wind Engineering and Industrial Aerodynamics 139: 111-123.
[7] Firdaus R, Kiwata T and Kono T. et al 2015 Numerical and experimental studies of a small vertical-axis wind turbine with variable-pitch straight blades J. Journal of Fluid Science and Technology 10(1): JFST0001-JFST0001.
[8] Rezaeiha A, Kalkman I and Blocken B 2017 Effect of pitch angle on power performance and aerodynamics of a vertical axis wind turbine J. Applied Energy 197: 132-150.
[9] Qiuping Yang and Deke Xi 2017 Study on the influence of blade installation angle on aerodynamic performance of H-type vertical axis wind turbine J. Acta Energiae Solaris Sinica 38(09): 2544-2551.
[10] Siyue Qian, Zhenzhou Zhao, Chen Tian, Ruixin Wang, Guanyu Zeng and Yuan Zheng 2018 Numerical simulation of new variable-pitch strategy for H-type wind turbine J. Journal of Drainage and Irrigation Machinery Engineering 36(03): 230-236.

[11] Lijun Zhang, Dongchen Ma, Xinhui Zhao, Yuxia Mi, Song Zhang, Hanxiang Wang and Hao Jiang 2018 Real-time variable-pitch control laws of H-type vertical axis wind turbine under dynamic stall J. Journal of Central South University (Science and Technology) 49(10): 2610-2617.