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Wind tunnel experiments for innovative pitch regulated blade of horizontal axis wind turbine

Wei Xie [1], Pan Zeng*, Liping Lei [1]

Key Laboratory for Advanced Materials Processing Technology of MOE, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

In current study, innovative pitch regulated blade model with folding outer blade section to control power output was made. A small wind turbine rotor with three innovative blades was tested in a low speed wind tunnel to validate the blade effectiveness. The main objective of current study is to investigate this blade performance in limiting power growth in high wind speed and to discuss its mechanism to control power. All the experiment data are inclusive of wind tunnel blockage correction and blade performance is assessed in terms of power output and power coefficient. It is found that when the outer blade section is folded, decrease of both blade energy conversion efficiency and wind energy contained in the airflow that passes through the rotor leads to power output reduction. The highest power coefficient of tested blade is 0.23 and can be reduced by the maximum of 82.8% through folding control. A constant power output in high wind speed is achieved with the tested blade and corresponding fold angle control rule is acquired.

1. Introduction

With the development of industry and the change of human daily life, energy demand is expanding rapidly. The consumption of wind power is increasing worldwide due to the fossil fuel supply deficiency and concerns about global warming. According to the data from GWEC (Global Wind Energy Council) [1,2], total cumulative wind generating capacity stands at 369.553 GW at the end of 2014 and wind power is expected to account for 17–19% of the global electricity supply by 2030. Among various wind power machines, the HAWT (horizontal axis wind turbine) plays a key role and the pitch regulated wind turbine is a basic type. This type of wind turbine possesses the ability to control blade pitch and thus is capable of maintaining constant power output in high wind speed. Besides, it has advantages in active start-up and aerodynamic brake, which is not achievable for its counterparts [3]. The wind turbine power control is realized by regulating rotor power coefficient (Cp). According to wind conditions, pitch regulated wind turbine adjusts Cp by pitching blade and therefore controls power output [4].

In recent years, the generator RCC (rotor current control) technology has also been used as assistance to pitch control. Under fast changing wind conditions, RCC takes charge to control power output while blade pitch control kicks in when wind speed becomes relatively stable [5–7]. Using RCC technology usually involves doubly-fed induction generator and control system is designed to realize favorable power output. In the study conducted by Belmokhtar et al. [8], a fuzzy logic control system was developed. This new control method was reported to possess the ability to track the maximum power point and the power converter size was reduced as compared to the conventional method. In the field of control system robustness, Song et al. [9] studied an adaptive disturbance rejection controller. The controller was capable of driving the rotor current to track the reference value under conditions such as grid disturbances and parameter uncertainties. Besides RCC technology, by modifying wind turbine blade shape, the blade power output performance can also be changed. The influence of blade extension on power performance has been investigated by Imraan et al. [10]. A telescopic type wind turbine blade was proposed and analyzed experimentally and computationally in their study. The research results indicated that by extending blade length, the blade power output increased considerably. In the study made by Lanzafame and Messina [11], the twist angle of a wind turbine blade was designed and the blade power curve was evaluated based on the blade element

* Corresponding author. Tel.: +86 10 62794261; fax: +86 10 62773637.
E-mail address: zengp@mail.tsinghua.edu.cn (P. Zeng).
[1] Tel.: +86 10 62794261; fax: +86 10 62773637.

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Nomenclatures

α	angle of attack [°]	Cr	driving coefficient
β	pitch angle [°]	D	wind turbine rotor diameter [m]
γ	incline angle [°]	e	energy conversion efficiency
η	fold angle [°]	E	free stream wind energy [W]
ρ	air density [kg/m^3]	f	blockage correction factor
φ	relative wind direction angle [°]	Fd	drag force [N]
Ω	blade angular speed [rad/s]	Fl	lift force [N]
a	axial flow induction factor	n	rotation rate [r/min]
a′	tangential flow induction factor	P	power output [W]
A	wind turbine rotor swept area [m^2]	P_{max}	maximum power output [W]
B	number of blade	r	blade element rotation radius [m]
C	length of chord line [m]	R	length of blade span [m]
Cd	drag coefficient	Re	Reynolds number
Cl	lift coefficient	T	rotation torque [Nm]
Cp	power coefficient	TSR	tip speed ratio
		V	free stream wind speed [m/s]
		W	relative wind speed [m/s]

momentum theory. By optimizing blade twist angle, the optimized blade was found to have better power output performance especially after blade tip stall occurred as compared to the original one. Kishinami et al. [12] conducted a research on the aerodynamic characteristics of wind turbine blade from both theoretical and experimental aspects. Their study demonstrated that the dependence of blade power coefficient on the blade pitch angle was related to the blade airfoil shape. The wind turbine power control can also be achieved by simply pitching the tip blade section [3]. Research conducted by Shimizu et al. has indicated that blade tip is crucial to rotor power performance [13]. Partial pitch wind turbine has been reported to possess the capability to control power output and has shown advantages in alleviating pitch actuating duty [14]. Some partial pitch wind turbine inventions have already been patented [15,16] and prototype of this kind wind turbine has been constructed. Envision Energy Co., Ltd. designed and installed the first prototype of two-blade, partial-pitch off shore wind turbine [17]. Numerical analysis and wind loads data collection on this wind turbine have been conducted. It is found that compared to full span blade pitch control, wind loads on rotor is reduced and favorable power regulation performance is acquired by partial blade pitch control [18–20].

Based on these findings, the outer blade section is crucial to the wind turbine power output and by adjusting the pitch angle of the outer blade section, wind turbine power control can be realized. An innovative pitch regulated blade with folding outer blade section was proposed. This proposed folding blade is treated as a new kind of blade that controls power output actively. The innovative pitch regulated blade with folding outer blade section to control power output was made. A small wind turbine rotor with three innovative blades was tested in a low speed wind tunnel to validate the blade effectiveness. The main objective of current study is to investigate the blade performance in limiting power output growth in high wind speed and to study its mechanism to control power. The fold angle control rule to realize constant power output of the tested blade is also obtained.

2. Description of innovative pitch regulated blade

The schematic of the innovative blade is shown in Fig. 1. The blade comprises a fixed inner blade section and a folding outer blade section. The outer blade is connected to the inner blade and can be folded out of blade rotation plane. The blade characteristic

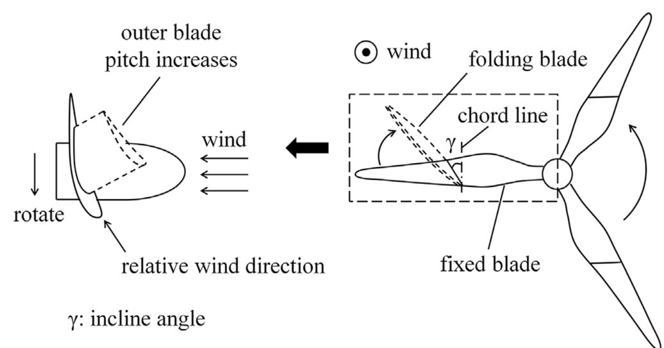

Fig. 1. Schematic of innovative pitch regulated blade.

consists in the fold axis that intersects blade chord line with an incline angle (γ) as shown in Fig. 1. Due to the inclined fold axis, when outer blade is folded, its pitch angle (β) increases. As a result, blade energy conversion efficiency is adjustable. Furthermore, rotor swept area diminishes as the outer blade is folded, which reduces wind energy available for exploitation. Based on these factors, blade power output regulation can be achieved by outer blade folding control. Current study focuses on validating this innovative blade feasibility on controlling power output. Small folding blade models with manual folding device are made and tested to offer experiment data. The designs of folding actuating device, folding control system and blade structural layout are not in the consideration.

The small wind turbine rotor tested in the wind tunnel is shown in Fig. 2. The rotor is composed of three innovative blades and the diameter is 0.8 m. Each blade comprises of a 0.18 m fixed inner blade section and a 0.17 m folding outer blade section. The inner blade section and the outer blade section are cut from a commercial blade. The outer blade is then connected to the inner blade using a manual folding device. The outer blade can be folded at desired fold angles (η) with the minimal angle increment of 5°. Incline angle (γ) is designed as 30° and three blade fold angles are adjusted identically in wind tunnel experiments. The blade is made of engineering plastic and the folding device is made of steel. Fig. 3 shows side views on the blade tip with different fold angles. As can be seen, when outer blade is folded, its pitch angle increases.