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Study on small wind turbine icing and its performance

Lichun Shu, Jian Liang *, Qin Hu, Xingliang Jiang, Xiaokai Ren, Gang Qiu

State Key Laboratory of Power Transmission Equipment and System Safety and New Technology, College of Electrical Engineering, Chongqing University, Shapingba District, Chongqing, China

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ABSTRACT

Wind turbines often suffer from severe ice during winter. Ice on the blades changes the airfoil profile, thereby causing wind turbine power loss. The icing characteristics and output of small horizontal-axis wind turbine were experimentally studied in an artificial climate chamber, and a 3D ice accretion wind turbine model was proposed to simulate glaze ice. Results show that ice rapidly reduces the rotation speed and load power of the wind turbine. The ice growth rate rises initially and then declines with time. Ice linearly increases from the root to the tip and mainly accumulates at the leading edge. As the rotation speed slows down, the ice-covered area moves to the pressure side. Higher wind velocity and lower temperature lead to more severe ice, but they do not change the ice shape. The shaft torque of the iced turbine shows a rising trend, and then it falls, thereby decreasing the shaft power and power coefficient. Ice load seems to have a greater effect than the deterioration of aerodynamic characteristics on the rotor performance of small wind turbines.

1. Introduction

As the most economically competitive energy, wind power plays an important role not only in the diversification of energy security but also in greenhouse gas emissions. Wind turbines often suffer from severe ice in winter. Ice changes the shape of the blade and surface roughness. Ice on the leading edge greatly deteriorates the aerodynamic characteristics of the blade, thereby leading to serious wind turbine power loss (Botta et al., 1998; Etemaddar et al., 2014). Power loss caused by freezing was evaluated as 24–27% for 5 MW wind turbines NREL in Northern Europe (Homola et al., 2012). During winter, wind turbines in China are often shut down because of severe ice.

Some ice accretion wind turbine models have been proposed in recent years, such as TURBICE, LEWICE, and FENSCAP-ICE (Makkonen et al., 2001; Reid et al., 2013; Wright, 2008). TURBICE and LEWICE were mainly used in 2D ice prediction. FENSCAP-ICE developed a 3D method with a single-step computation. Rime ice simulation by FLUENT also showed valid results for ice prediction (Fu and Farzaneh, 2010; Sagol et al., 2012). Most ice investigation has been performed on megawatt turbines (Virk and Homola, 2012; Virk et al., 2010a). However, hectowatt turbines also play an effective role in cities. Bose (1992) experimentally studied the ice profiles of a small horizontal-axis wind turbine blade at different spanwise positions. Han et al. (2012) used a rotating device attached with blades to verify LEWICE under different icing conditions.

In this paper, the icing characteristics and output of small horizontal-axis wind turbine were studied. The rotation speed, load power, and ice shape were recorded in artificial icing tests under various icing conditions. A 3D ice accretion wind turbine model was proposed to predict the glaze ice by using FLUENT and verified through tests. Shaft torque changes of the iced turbine were numerically analyzed on the basis of the model. This paper provides a 3D model for glaze ice accretion and calculates the aerodynamic characteristics of the changes of small wind turbines. The results provide reference for de-icing design.

2. Test and ice accretion model

2.1. Test facility and conditions

The icing test was conducted in an artificial climate chamber as shown in Fig.1(a). The multifunctional artificial climate chamber, which has an internal diameter of approximately 7.8m and an internal height of approximately 11.6 m, simulate different atmospheric icing environments (Shu et al., 2012). An ice wind tunnel was designed for a small horizontal-axis wind turbine, which provides a maximum wind velocity (V) of 10 m/s. The blade radius (R) is 0.5 m, and the chord (c) is 0.03–0.1 m as shown in Table 1. The three-phase permanent magnet synchronous motor output is 100 W under a rated condition. The relation between wind velocity and power was measured by tests shown in Fig.1(d). Ignoring the rectifier and battery, the output side was directly connected with the three-phase triangle resistance. The electrical load was obtained by measuring the current and voltage through the multimeter. Given the lack of feedback loop, the rotation speed (n) was variable and measured by laser speed measurement in the icing test.

The environmental parameter in the icing test was set as shown in Table 2, and the ambient temperature (T) and V were the two variables.

* Corresponding author.
E-mail address: liangjian0720@163.com (J. Liang).

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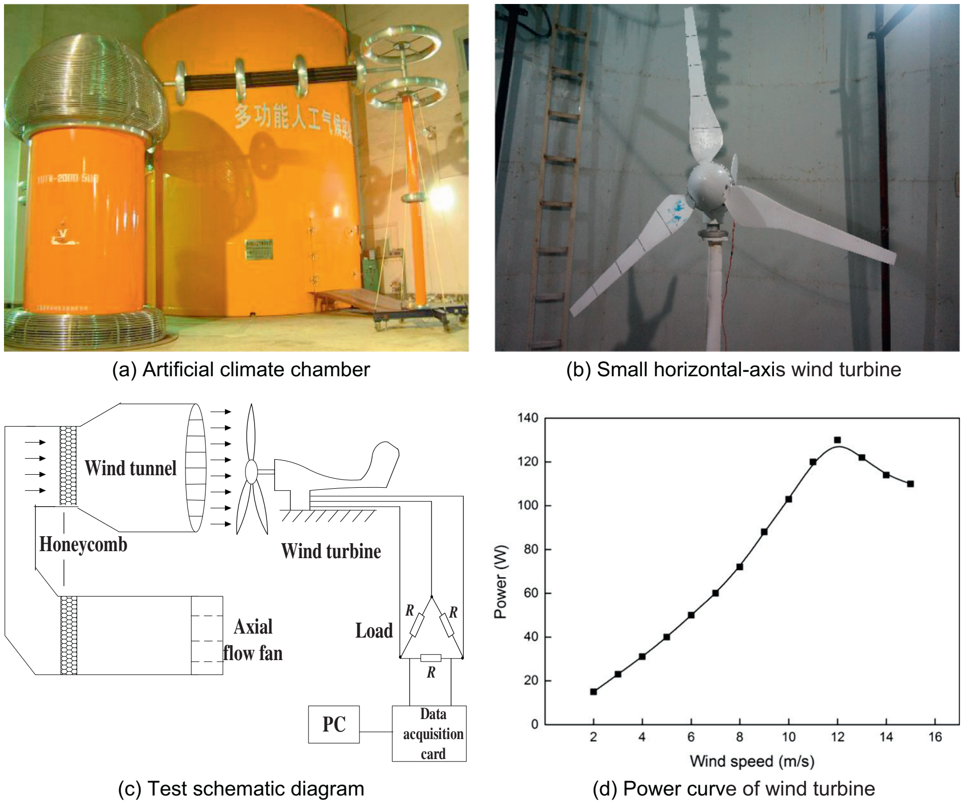

Fig. 1. Test facility (a) artificial climate chamber (b) small horizontal-axis wind turbine (c) test schematic diagram (d) power curve of wind turbine.

T was adjusted by the controller of the climate chamber, and *V* was variable by adjusting the distance between the wind tunnel and wind turbine. The median volume diameter (MVD) describes the average droplet size, which was adjusted by adding air into the spraying nozzle. To statistically measure it, the freezing droplets were imaged under a microscope and computed with a hemispherical formula. Liquid water content (LWC) represents the water concentration in the air and was measured by a slowly rotating multicylinder (Mazin et al., 2001). LWC was related to the ice thickness of the cylinder under rime ice condition. The obtained aerodynamic characteristics deteriorated, and the rotation speed reduced under icing condition. The overall icing time in each test was determined by monitoring the rotation speed down to 0.

Table 1
Blade geometry parameter.

Blade	r/R	Chord length (m)	Twisted angle (°)	Airfoil profile
	1	0.03	7	NACA4409
	0.8	0.035	10	NACA4409
	0.6	0.045	15	NACA4409
	0.4	0.055	20	NACA4409
	0.2	0.1	25	NACA4409