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Characteristics of ice accretions on blade of the straight-bladed vertical axis wind turbine rotating at low tip speed ratio

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ABSTRACT

Icing on blade surface of wind turbine greatly affects the performance of wind turbine which becomes a very serious problem for the wind turbine installed in cold and wet regions both for larger-scale wind turbine and small-scale ones. The Straight-bladed Vertical Axis Wind Turbine (SB-VAWT) is a kind of lift-type VAWT which is widely used for small-scale wind power generation. Icing on blade of SB-VAWT will also affect both the starting performance and out power performance. To verify the icing characteristics of blade rotating at low tip speed ratio of the SB-VAWT during its starting stage, wind tunnel icing experiments have been carried out on a rotor with blade airfoil of NACA0018 in a wind tunnel icing experimental system by using natural low temperature in winter proposed in this study. The icing distributions were recorded by a high speed camera at different tip speed ratios from 0 to 1. The weight of icing on blade was also measured. Furthermore, the icing area ratio and icing rate were calculated and analyzed. The main results show that the ice accretion on a rotating blade of SB-VAWT at low tip speed ratio is quite different from the blade in static condition. The icing distributed on the whole surface of blade and the icing area increases along blade airfoil outline with the increasing of icing time and rotational speed. The whole weight of icing on all blades of wind turbine increased with the increasing of blade number.

1. Introduction

With rapid development of large-scale wind turbine, the small-scale off-grid wind turbine has also been concerned in recent years. There are many types of wind turbines. According to the position of rotor shaft relative to tower or ground, wind turbines can be classified into Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). With the development of aerodynamic theory of aircraft and being applied successfully for years, the HAWT becomes the most popular wind turbine in the world, especially in the large scale grid-connected wind power generation. In modern society, with rapid development of small-scale wind turbine for distributed generation and off-grid wind power market, there is resurgence of interests in VAWT by researchers again which is mainly due to the characteristics of independence from wind direction comparing with the HAWT (Paraschivoiu, 2002). Among all kinds of VAWTs, the Straight-bladed Vertical Axis Wind Turbine (SB-VAWT) has the advantages of simple configuration, low cost and good efficiency. It becomes one of the widely researched VAWT in recent years (Islam et al., 2008). Previous studies show that the SB-VAWT has more advantages when it serves to the small-scale wind turbine which is one of the most important renewable energy resources for people living in urban area and countryside.

However, for the wind turbine installed in cold regions, icing on blade is a very serious problem in cold and wet climate which greatly affects output performance of wind turbine and leads to safety accident (Laakso et al., 2005; Nalili et al., 2009; Homola et al., 2012; Etemaddar et al., 2014). Two examples of wind turbine icing are shown in Fig. 1. Fig. 1 (a) shows the icing on HAWT photographed in Sichuan Province of China and Fig. 1 (b) shows the icing on SB-VAWT located in Tottori, Japan. Now there are some researches having been done on problem of icing on blade for HAWT (Bose, 1992a; Bose, 1992b; Matthew et al., 2010; Kraj and Bibeau, 2010a; Kraj and Bibeau, 2010b). However, the characteristics of icing on blade of HAWT are not suitable to the VAWT, because the working principle and the configuration of rotor are quite different between the HAWT and VAWT. Therefore, the effects of icing on VAWT should be researched. According to the previous researches, only the characteristics of icing on static blade of VAWT have been studied (Li et al., 2014), the icing on a rotating blade of VAWT has been seldom reported.

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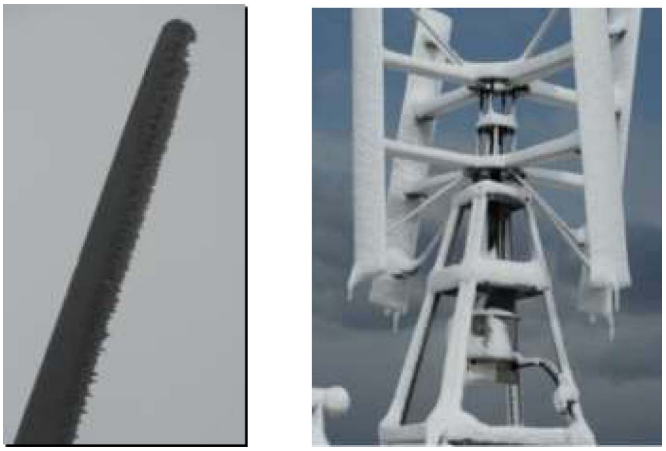

(a) HAWT (b) VAWT

Fig. 1. Examples of icing on wind turbine blades.

Based on the previous researches (Paraschivoiu, 2002), the power performance of SB-VAWT has two characteristics that are also two problems in some sense. 1) The aerodynamic performance is not good for the tip speed ratio from 0 to 1, which means that the SB-VAWT has bad starting performance than HAWT. 2) The maximum power coefficient is lower than that at the high tip speed of 3 or 4. Therefore, the researches on SB-VAWT recently mainly focus on the two directions, the increasing of output power performance at high tip speed ratio and the improvement of starting performance at low tip speed ratio. In this research, only the icing effects are focused on the starting performance of SB-VAWT when wind turbine is used in cold climate regions. The researches on icing effects on rotating blade with high tip speed ratio will be carried out in future work.

There are two methods of researching on icing of wind turbine, they are the experimental method using icing wind tunnel and simulation method (Han et al., 2012; Villalpando et al., 2012). Due to high demand of equipment and environment, high cost and complex experimental process of icing wind tunnel test, the simulation is more popular and used as main method to research on icing on blade now. In this paper, a new experimental method is proposed by using natural low temperature in cold region (Li et al., 2016). A common wind tunnel was reformed by equipping some instruments to supply icing conditions. The experiments have been carried out in winter because the low temperature for icing can be obtained from natural environment which omits the refrigeration system. The main parameters of this reformed icing wind tunnel such as liquid water content (LWC) and temperature have been measured and satisfied the experimental conditions based on verification tests (Li et al., 2016). A model of rotor with different blade numbers of small-scale SB-VAWT was designed and made for icing test. Experimental researches on the characteristics of icing distributions on blade surface of the test rotor have been carried out in this icing wind

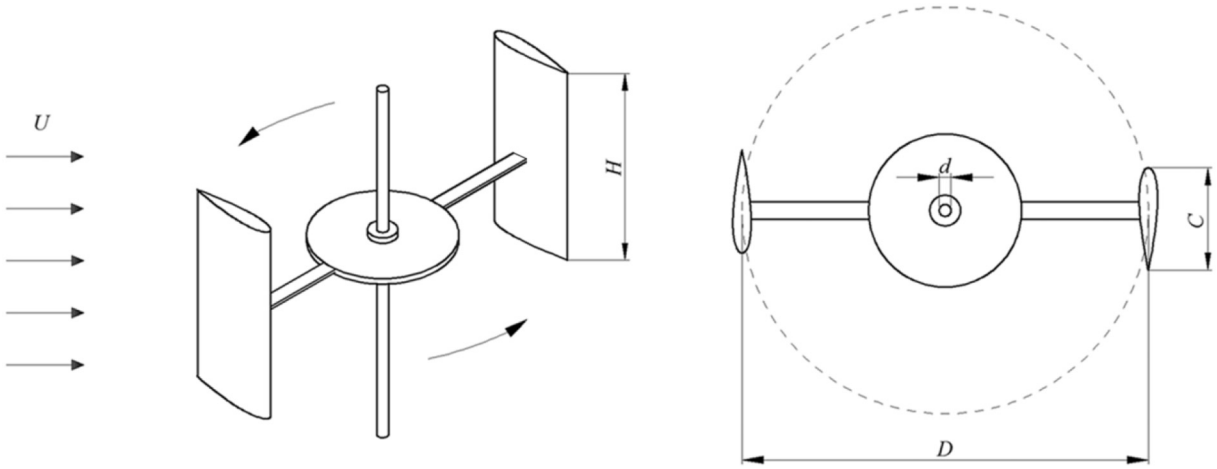

Fig. 2. Schematic diagram of model rotor.

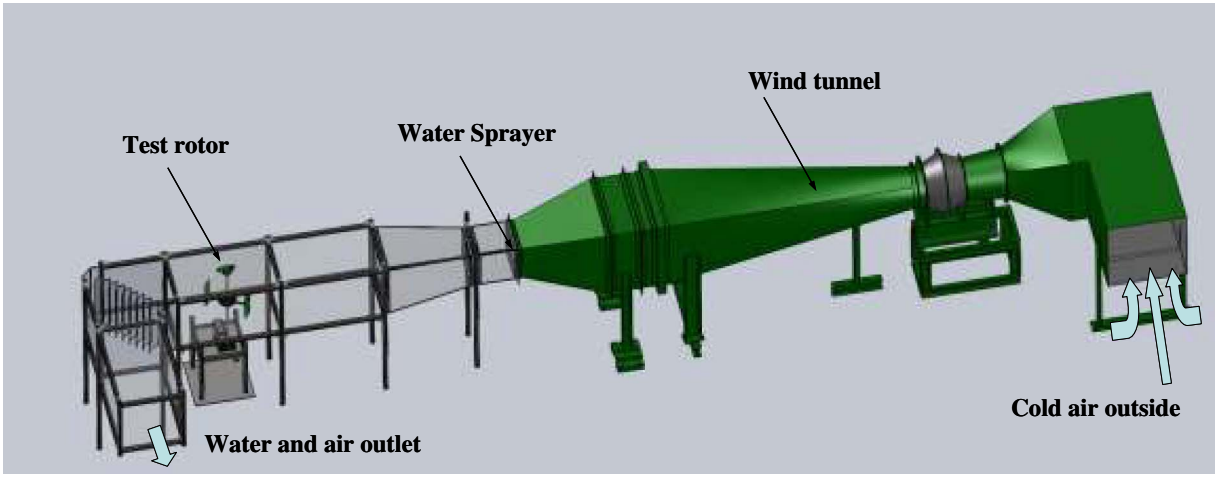

Fig. 3. Schematic diagram of wind tunnel icing experimental system.