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Study of ice accretion feature and power characteristics of wind turbines at natural icing environment

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ABSTRACT

Wide cold regions with high air density as well as wind speed are much beneficial for the wind energy exploitation. However, wind turbines in these regions always suffer a series of icing issues, especially the blade aerodynamics degradation and much production loss in winter. Therefore, the paper aims to study the ice accretion feature on blades and the effect of ice severity on the power performance of wind turbines at natural icing environment. The ice distribution on the blade is analyzed quantitatively in the image processing method, and it is found that the ice thickness on the blade increases rapidly from the root to the middle of the blade, and then slowly from the middle to the blade tip. In the icing duration period, both the pitch angle and rotor speed of the wind turbine fall remarkably at the same wind speed, and the pitch angle shows more sensitive to the blade icing for wind turbines with the traditional control strategy. Based on the statistical operating data of the 300 kW wind turbine in different icing cases, the rotor performance deteriorates more seriously as the ice thickness of the blade increases, which changes the original matching relation between the rotor and generator. In addition, the ice thickness of the leading edge at $r/R = 0.95$ shows great correlation with power loss in given icing cases, and this correlation still needs to be studied further at more icing events. The results can provide a reference for the operation performance of wind turbines in cold regions.

1. Introduction

Wind energy in cold climate areas are becoming popular throughout the world, due to its high air density and wind potential [Battisti et al., 2015]. However, wind turbines in these regions exposed frequently to icing events during the cold seasons, which usually bring about devastating impacts [Parent and Ilinca, 2011]. Extra loads and vibration from ice accretion shorten the component life of blades, and higher noise levels may break the associated environmental restrictions. Besides, there are implicit health and safety risks from ice thrown on blades. Finally, the aerodynamic properties and generating power of iced wind turbine blades are heavily affected, which even result in forced shutdown of wind turbines [Fikke et al., 2006; Dalili et al., 2009; Fakorede et al., 2016].

In order to analyze the power production loss after icing, a large number of researchers performed experimental studies combined with the numerical simulation. References [Horák et al., 2008; Duncan et al., 2008; Mortensen, 2008; Barber et al., 2010; Virk et al., 2010] indicated that ice accretion on blades results in a reduced lift coefficient and increased drag coefficient of profiles, resulting in the power loss. Homola et al. (2010, 2010) analyzed the effects of temperature and droplet size variation on the rate and shape of ice growth, and found the power loss is more prominent for the case of glaze ice compared to rime ice. Erik (2010) utilized both statistical and physical approaches to study the relationship of modeled ice load and actual production loss. Malmsten (2011) proposed a quantitative analysis method to reflect the overall icing trend and further forecast the production loss in winter. Han et al. (2012) researched the effects of ice severity on wind turbine torque through ice accretion tests. Jha et al. (2012) put forward the turbine icing operation control system (TIOS) involving the ice accretion modeling, the analysis of airfoil and wind turbine performance. Alberts (2012) established the matrix of blade icing frequency to describe the relationship between icing frequency and atmospheric parameters, and then predict electric energy loss in icing climate. Lamraoui et al. (2014) indicated that the outer part of the blade contributed significantly to the blade aerodynamics and the power degradation can reach a maximum of 40% under icing conditions.

In terms of ice detection, using relative humidity, temperature and dew point sensors may give a good idea when the icing event will occur [Laakso et al., 2005; Tammelin et al., 2005]. For wind turbines, it is popular to adopt optical ice detectors and double anemometry to detect the presence of ice, because they are not expensive and give a good

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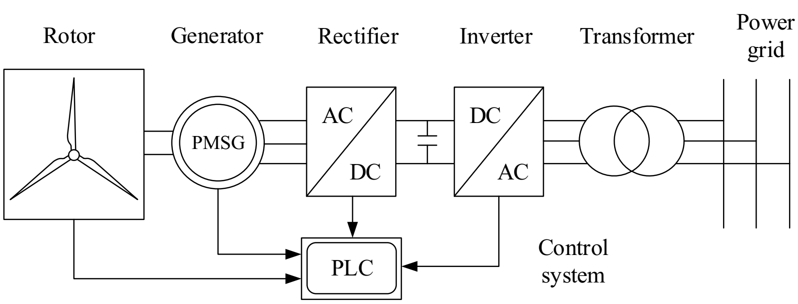
(a) 300kW wind turbine and control room.



(b) Schematic diagram of the test.

Fig. 1. 300 kW wind turbine test system. (a) 300 kW wind turbine and control room. (b) Schematic diagram of the test.

overall picture of the severity and duration of the icing event [Parent and Ilinca, 2011]. However, there is still few reports on the ice thickness of the blade measurement [Akhloufi and Benmesbah, 2014]. Besides, the unique meteorological conditions of wind fields in the southern of China is less concerned in previous study on icing effects. What is more, there is still considerable uncertainty of the actual power generation loss [Seifert, 2003] and no clear connection was found between measured power loss and modeled ice loads when analyzing available data in icing environment [Erik, 2010].

Therefore, the purpose of the paper is firstly to research ice accretion feature at natural icing environment in the image processing method. Both actual ice distribution along the blade and effects of atmospheric icing parameters on blade icing are analyzed in detail based on the field observation. Moreover, dynamic response including the rotor speed, pitch angle and power output during icing duration time are measured. Finally, generating power performance in short-time are investigated in the improved bins method and effects of ice thickness at blade tips that is a representation of ice severity on rotor speed, power and moment coefficients are discussed.

2. Icing feature of wind turbines in icing events

2.1. The test equipment and object

The natural icing test station in the paper locates in Xuefeng Mountain, Hunan, southern of China, which has a typical microweather icing climate with the altitude of 1400 m and more than 90 days of icing periods in a year. The experiment work was carried out on 300 kW variable-pitch and variable-speed wind turbine in January 2017. The total number of icing events accounts for one third of the month, and 6 icing cases of them were chosen for the detailed analysis of wind turbine operation. For this 300 kW wind turbine, actual production loss in icing climate usually accounts for more than 20% of annual production. Therefore, the ice class of this site can be regarded as the highest of Level 5 according to IEA ice classification [Baring et al., 2012]. Fig. 1 shows the test wind power equipment and schematic diagram of the test.

The wind turbine rotor with 31 m diameter has three blades with series of NREL S819 tapered and twisted blade profiles (0°–25°). The rated wind speed is 13 m/s and rotor speed is 44 rpm. Besides, the blade with 14.6 m length has the root diameter of 0.68 m, the largest profile chord of 1.414 m and tip chord of 0.363 m. The VSCF (variable speed constant frequency) wind power generation system is applied to the wind turbine, aiming at acquiring the maximum wind power conversion efficiency and ensuring the output voltage and frequency stability. In order to realize the optimal coupling between the rotor and the generator, both rotor speed and pitch angle can be automatically adjusted based on the functional relation between wind speed and power output. Besides, operation parameters of the wind turbine such as wind speed, rotor speed, pitch angle and output power can be recorded as needed with 1 Hz sample frequency by German Beckhoff PLC controller that is widely used in wind power industry.

As is shown in Fig. 2, there are three observation windows as well as HD cameras installed at different heights of the tower, aiming at observing ice accretion on the tip, the middle and the root of the blade accurately and assessing ice severity comprehensively. In addition, the radius position from the root to the tip on each blade is marked by the red painting lines with an interval of 2 m, as is shown in Fig. 3. They will help us to identify the position of ice on the blade and get the right orientation of the blade for the measurement.

In terms of the measurement of environment parameters, BLF1-S wind sensor installed at the top of the wind turbine cabin is applied to