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Ice detection using thermal infrared radiometry on wind turbine blades

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ABSTRACT

Wind farms are located in areas with a high probability of ice occurrence. Icing involves problems such as energy losses, mechanical failures and downtimes. The priority is to detect icing in order to avoid these problems.

Icing detection is a complex procedure for example, low temperatures are not a guaranty of ice formation, and other variables may affect. Different techniques have been recently proposed to detect ice in wind turbine blades. They are mainly based on damping of ultrasonic waves on the blade surface, or measuring the resonant frequency of a probe. But these methods have some drawbacks that may cause the system to fail, e.g. the behaviour of ultrasonic waves in composite materials is difficult to predict due to different fibre orientations, and the ice detection by changes in the resonance frequency could lead to false alarms due to variations in working conditions.

This paper takes advantage of the remote sensing techniques to propose a novel approach for icing detection without physical contact. The approach is based on the drastic emissivity change that it is produced over a surface characterized with a low emissivity value when ice appears. An experiment was conducted using a broad-band thermal radiometer and a section of a wind turbine blade. Radiometric temperature measurements were collected over the blade with and without an aluminium foil patch. The piece of blade was cooled down and different scenarios were considered, including frozen with and without ice. This study was completed with a sensitivity analysis of the approach to dust accumulation, accounting for real operation conditions. Results show the feasibility of this technique to detect ice formation and discern between frozen and icing conditions.

1. Introduction

Wind energy is the most competitive renewable energy and the energy source with a more projection nowadays. Wind farms are located in areas with suitable wind characteristics, frequently prone to icing occurrence. Wind farms in these areas present problems related to icing such as energy losses, mechanical failures, downtimes, problems to access for human resources, measurement errors or safety hazards among others (see Fig. 1). The work carried out as part of the research project IcingBlades [1] shows that 18,966 MW h were lost over a period of 29 months as a sole consequence of blades icing up in a set of 517 wind turbines, with a total installed power of 682 MW. This energy lost is practically equivalent to the main stops together, e.g. change of multiplier, turbine change, etc. In Spain, with more than 21,000 MW installed, this phenomenon would be equivalent to a loss more than 550 GW h of power production, i.e. 45 million € every 29 months [1]. These production losses would be equivalent to the energy consumption of 200,000 households and savings of 658,682 tons of CO_2. Fig. 1 shows the main causes of the production energy losses, where ice on blades is the principal one. These energy losses involve an increment of the operation and maintenance (O&M) costs.

Onshore wind farms are usually located in elevated areas in order to get the maximum wind velocity [2,3]. These locations are often exposed to freezing temperatures, i.e. it presents multiple problems due to the icing blades, leading to power generation losses and costs [4,5]. The WECO (Wind Energy in Cold Climate) project analysed the ice effects, energy generation and icing in wind turbines [6,7]. It is estimated that 20% of the wind farms are installed in areas with high probability of icing [8].

Parameters such as temperature, wind speed, relative humidity or air density, among others, condition the ice appearance (see Fig. 2). A classification of different types of icing is presented in Ref. [9], discerning between in-cloud icing and precipitation and

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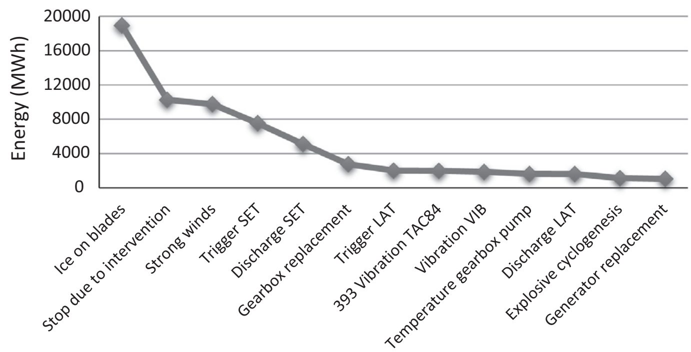

Fig. 1. Power losses due to different alarms in IcingBlades.

Fig. 2. Illustration of icing blades.

hoar frost. In-cloud icing appears when the atmospheric temperature is below 0 °C and the humidity is high. Super-cooled water droplets hit the surface of the structure and frozen at the time of impact. The main problem is the accumulation of different layers of this kind of ice.

Frost is the most common cause of ice appearance in wind turbines. It grows in all parts of the wind turbine but the onset occurs in the leading edge of the blades, owing the incident velocity [10].

The main problems due to icing blades are: Power loss by the reduction of aerodynamic efficiency; unbalanced loads on turbines; influence in the lifetime of the components; increased noise generated by blades; changes in blade surfaces by ice accretion; safety hazard and measurement errors [11].

The objective for the ice prevention or removal systems is the reduction of the wind turbine downtimes. The mitigated wind turbines are those with a system to deal with ice accretion. During the icing stage, the ice growth is controlled by the system installed in order to avoid the alarm, reducing the necessary downtimes to remove the ice from the turbine. When the accumulation is significant, the alarm appears and the wind turbine is stopped until the ice is removed. Downtimes are smaller than those in the non-mitigated machines. During post-icing the wind turbine can operate regularly [12].

This industry requires of significant improvements in reliability, lifetime or availability that it is done by an efficient maintenance based on condition monitoring systems [13]. Modern wind turbines need also an autonomous condition monitoring system because of the associated repair costs, especially for off-shore plants, where any repair actions can extend several weeks due to the difficult working conditions [2].

This paper presents a novel approach for operational icing detection based on thermal remote sensing. A thermal infrared sensor is used to measure the radiance emitted by the blade surface. The differences in terms of emissivity between ice and other materials allow the automatic and quick detection of ice formation by analysing the radiance values registered. The effect of dust accumulation in wind turbine has been also considered.

2. State of the art

2.1. Condition monitoring for icing blades detection

Traditional ice detection uses meteorological equipment that simply measures conditions for icing, but this does not detect ice on blades. It does not give operators enough information to take action such as shutting down the turbine to prevent damage [14,15].

Wind turbines should have a correct ice detection system to predict when the icing appears on the structure. Measurements are usually done on the nacelle, which generates false alarms when the ice volume varies radially and across the blade, or in a location into the wind farm. These measures are usually carried out in operating conditions providing overestimated values.

There are methods that detect certain parameters to find out the favourable conditions for the development of ice, e.g. the size of the droplets in suspension and the water concentration in the air, together with the temperature and wind speed. The main parameters that indicate the risk of freezing are the relative humidity and the air temperature.

Ice detection helps to increase the safety, reduce downtimes, increase reliability, availability and energy production, and decrease the costs associated with failures caused by icing blades. The ice detection techniques can be categorized as direct and indirect techniques as follow.

Direct techniques are those in which the measurement of ice is carry out on the surfaces of the wind turbine analysed, being the most important: Measurement of the resonance frequency [2]; damping of ultrasonic waves [16]; measurement of amount of ice [17]; optical measurement techniques [18]; measurement of temperature change; measurement of vibration damping of a diaphragm [19] and measurement of electrical properties [20].

The indirect techniques for ice detection include the data acquisition and comparison with historical data. This comparison is employed to determine the appearance of ice on the wind turbine. The most important indirect approaches are the following: Video monitoring; measurement of noise [21]; difference in actual and expected power output; comparison of heated and unheated anemometers [22]; dew point and air temperature; change of the resonance frequency of the blade of a wind turbine; prediction of ice and frost probability maps and direct measurement of liquid water content and mean volume of raindrops.