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Wind Tunnel Study of Electro-thermal De-icing of Wind Turbine Blades

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Most of the wind turbines operating in cold climates are facing icing events, but very few of them are equipped with blade de-icing systems, and few studies were performed and published on the characteristics of these systems. In order to optimize the design and power consumption of an electro-thermal de-icing system for wind turbine blades, an experimental setup was built and used to test the system under icing conditions in a refrigerated wind tunnel. The parameters of the de-icing control system consider only the convective heat transfer at the blade surface during ice accretion. Meteorological data are those gathered from Murdochville's experimental site in Canada. The blade airfoil is a NACA 63-415, and the icing conditions are scaled to be simulated in the icing wind tunnel section. The results show the relation among the meteorological conditions, the ridge formed by liquid water runback, the heating power and the airfoil surface temperature. The study provides useful data for the design of electro-thermal de-icing systems for wind turbine blade application.

NOMENCLATURE

A: surface of heating element, m^2
a: axial flow induction factor
a': tangential flow induction factor
c: blade chord, m
c_f: coefficient of friction
$c_{p\,air}$: specific heat at constant pressure, J/(kg · K)
d: test duration, min
h_1: heating coefficient, $W/m^2 °C$
LWC: liquid water content, kg/m^3
MVD: median volumetric diameter of water droplets, μm
P: electric power, W
r: current span position on blade, m
St: Stanton number
t: duration of icing event, min
T_{amb}: ambient temperature, °C
T_h: surface temperature (recorded by thermocouples), °C
T_c: target temperature (manually keyed in), °C
U_{rel}: relative wind velocity, m/s
U_t: tangential wind velocity, m/s
U_w: wind velocity at blade level, m/s
U_∞: free stream velocity, m/s
α: angle of attack, °
β: pitch angle, °
ρ_{air}: air density, kg/m^3
ω: angular frequency, rad/s

INTRODUCTION

In many countries, the wind energy production capacity has significantly increased in the last few years. For example, in Canada, the installed capacity increased by 54% in 2005 (240 MW) and doubled in 2006 (657 MW). This brings the installed wind energy power capacity in Canada to 1341 MW (CANWEA, 2006).

The Canadian and North European wind climatology is characterized by stronger winds and higher air density during the winter months, which is the reason wind energy production is most significant during this period. Plus, the mountainous and cold regions generally have a higher wind potential because of local wind regimes and lower temperatures. In these regions, mainly remote, it is possible to reduce the energy production cost and increase the energetic autonomy thanks to wind energy instead of fossil fuels' use.

In the meantime, the wind turbines facing higher winds and lower temperatures should be adequately equipped to face these extreme working conditions (Dustewitz, 2003). As an example, wind turbines working in cold climates are equipped with heated nacelles because their mechanical and hydraulic components cannot properly operate in very low temperatures. Ice and snow accretion, frequent in these regions, generates an overload for the whole wind turbine, and mechanical wear can be significantly accelerated. The stopping of the wind turbine during icing events can lead to a loss of up to 10% of annual production. Because the aerodynamic performance of the blades is significantly affected by accreted ice, it is important to consider de-icing systems. However, these systems are rarely used, mostly for economical reasons and technical drawbacks.

The current de-icing systems for wind turbines originate from the aircraft industry, and very few tests were performed to optimize their design, either in the laboratory or on site. Different technologies have been considered for wind turbine blades. LM Glasfiber developed a microwave system (Mansson, 2004), while the Goodrich Corp. (2003) tested a pneumatic de-icer. However, the airflow and electro-thermal de-icers are mostly used because they represent fewer modifications of the wind turbine blades and because their technology is well known. The airflow de-icing system, commercialised by Enercon, blows hot air into the blade. The heating is homogeneous but the efficiency decreases with blade length increase (Hau, 2006). Consequently, the system is not of interest for large blades and in extreme conditions.

The electro-thermal de-icer is used in some sites, such as Canada's Yukon and Finland's Pori and Olostrunturi (Laakso et al., 2003). The system can be easily installed on existing blades. The significant energy consumption is its main drawback. In Pori, the system was used for public safety reasons and the power consumption was 1% of annual production (average between

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