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AERODYNAMIC SHAPE OPTIMIZATION FOR REDUCING ICE INDUCED LOSSES ON WIND TURBINE BLADES

Ozcan YIRTICI*, **Ismail H. TUNCER**†

* † Middle East Technical University (METU)
Department of Aerospace Engineering
06800 Ankara, TURKEY
e-mail: oyirtici@ae.metu.edu.tr
e-mail: ismail.h.tuncer@ae.metu.edu.tr

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Abstract. Ice accretion on wind turbines modifies the blade shape profile and causes alteration in the aerodynamic characteristics of the blades. The objective of this study is to optimize the blade geometry to reduce performance losses by minimizing ice accretion in cold climate regions and mountainous areas where wind energy resources are plentifully found. In this study, The Gradient Based Optimization Method and Blade Element Momentum Method will be employed together with an ice accretion prediction tool for estimating the power production of wind turbines both for iced and clean blades. The momentary power production loss is investigated by comparing the difference between power curves of the clean and iced turbines. It is inferred that the blade profile is one of the crucial parameters for icing and by modifying the blade geometry power production losses can be reduced.

1 INTRODUCTION

Wind resources in cold climate regions and highlands are typically good and making them attractive for wind energy. However, the formation of ice on wind turbines degrade the aerodynamic performance of the initial turbine blades by changing the aerodynamic characteristic of the blades. Icing related power production losses on a wind turbine depends on the atmospheric icing conditions, type and size of the wind turbine, and operation conditions.

Ice accretion over the rotating blades build up mostly on the leading edge of the blades and can cause critical unbalanced loads on the wind turbine. This situation enlarge material fatique, bring down the operational life of the turbine. Also icing on wind turbine causes ice throw and ice fall of wind turbine and makes the noise louder. In the horizontal axis wind turbine, aerodynamic performance losses are similar to that observed by wings and helicopter rotors under icing conditions [1].

In order to prevent or mitigate icing effects on wind turbines active or passive anti-icing and de-icing systems (ADIS) can be used (Figure 1), but few are available on the market. ADIS are generally based on heating, therefore wind turbines need more power to operate. Using shape optimization to design sectional blade profile for minimum ice accretion is a

Figure 1: De-icing of turbine blades [2].

critical issue for the wind turbines located in the cold climate region. In addition, it is possible to set up a cost effective ADIS system, based on the predicted ice shapes. This would optimize power production under icing conditions. In this study, an ice accretion prediction tool with BEM Methodology is used to predict ice shapes on turbine blade sections and to predict power losses under atmospheric icing conditions. A Gradient Based Optimization Algorithm is coupled to this model, to optimize the wind turbine blade profile shapes in order to minimize the ice accretion and the corresponding power production losses.

2 METHODOLOGY

In this study, a gradient based shape optimization algorithm is developed to reduce the ice accretion on wind turbine blades and to maximize the power production as a result. The Blade Element Momentum (BEM) method coupled with the 2D potential flow solver with viscous effects, XFOIL, is employed [3]. The BEM tool calculates the objective function of the optimization process, which is the power production of the turbine. XFOIL supplies the sectional aerodynamic loads including viscous effects under the local flow conditions. The ice accretion prediction tool predicts the ice shapes of the sectional blade profiles for the given atmospheric icing conditions.

3 RESULTS and DISCUSSION

This is a follow-up work of previous studies and more validations can be found about ice accretion predictions in [3, 4]. In this study, the ice accretion and power loss predictions are first carried out, then the optimization of a blade profile for the maximization of the power production under an icing condition is performed.

3.1 Power production losses on the Aeolos 30 kW Wind turbine due to icing

In this case, ice accretion prediction code is used to predict 2D ice profile shapes on the blade at 17 different span-wise locations for the Aeolos-H 30kW wind turbine. Operating conditions for this turbine are given in Table 1.

Table 1: Parameters used to define icing profiles

Airfoils	DU93-W-210
Rotational speed	120 rpm
Rated speed	11 m/s
Root chord	0.703 m
Tip chord	0.02 m
Turbine diameter ,R	12 m
Twist	17.45 degrees (max.)
Mode of control	variable speed/yawing
Liquid water content, LWC	0.05 g/m^3
Droplet diameter, MVD	27 μm
Ambient temperature, T_a	-10.0°C
Exposure time, t_{exp}	20, 40, 60, 80 minutes
Ambient pressure, p_∞	95610 Pa
Humidity	100 %

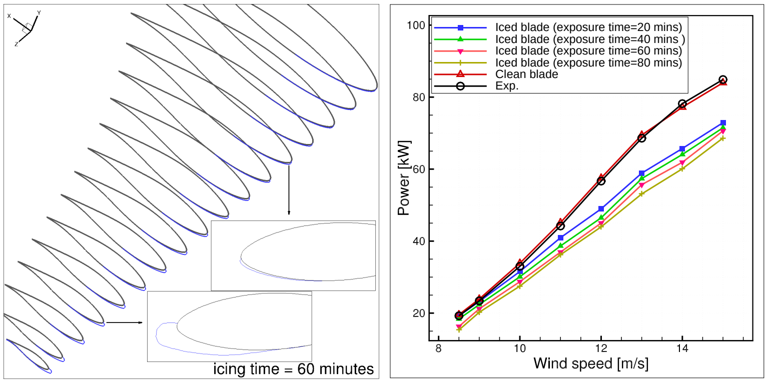

Figure 2: Predicted ice shapes at 11.0 m/s for for Aelos wind turbine for conditions in Table 1 (left), Predicted power curve and related power losses with respect to icing exposure (right).

Predicted ice shapes at 11.0 m/s for one hour exposure and the power curves for Aelos wind turbine are given in Figure 2. It is seen clearly that the ice shape grows with increasing span due to the increasing sectional velocity and decreasing sectional chord length. This change is caused by ice accretion has the potential to degrade the aerodynamic performance of the blade, especially near the tip sections.

Results in Figure 2 suggest that the power losses increase as the wind speed and icing exposure increases. Ice formation reduces the sectional lift and possibly causes premature flow separation on the blade and results in up to 19 % power production loss.

3.2 Optimization of blade profile

In this section, the optimization of the blade profile around the leading edge is performed using three bump functions on each upper and lower surfaces, Figure 3. In the gradient vector evaluations, 20 min exposure to the atmospheric icing conditions at 11 m/s wind speed are considered. The blade profile is modified by a simple line search algorithm following the evaluation of the gradient vector. The evaluation of the gradient vector and the modification of the blade profile continue until the change in power production is less than 0.1%. Figure 4 shows that the blade profile plays a significant role in ice formation related power losses, and it can be optimized in order to minimize these losses.

In the full version of the paper, a multi-objective optimization algorithm will be imple-

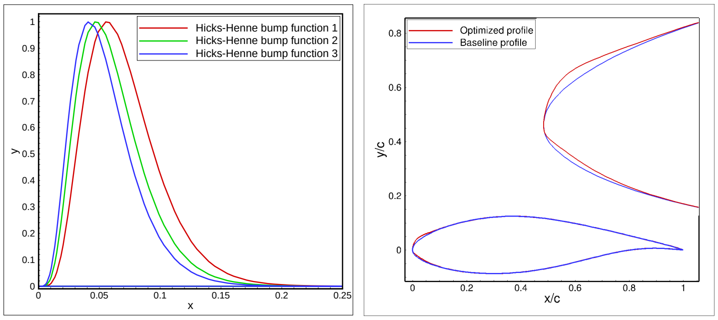

Figure 3: Bump functions (left), Aeolos wind turbine baseline blade profile (DU93-W-210) and the optimized profile (right).

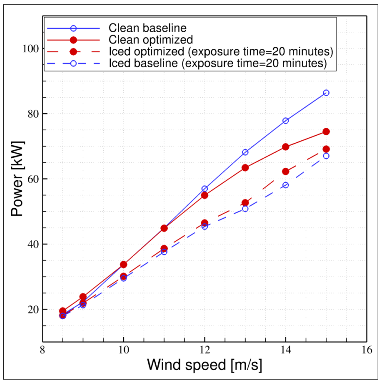

Figure 4: Power production of Aeolos 30 kW wind turbine

mented in order to improve the performance of the clean optimized blade profile. The profile optimization will first be constrained within 15% chord length from the leading edge of the section. The sectional airfoil profiles will be modified smoothly by means of different bump functions, Figure 3.

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