Wind-Energy Science, Technology, and Research
Industry/University Cooperative Research Center

Modeling of Power Losses due to Leading Edge Erosion

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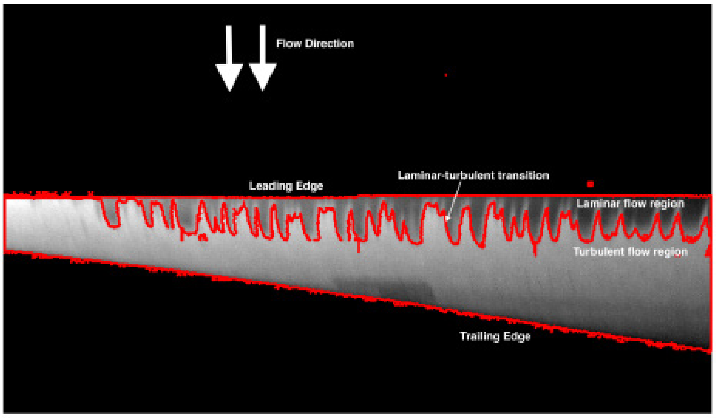
Due to operation under harsh conditions, rotor blades suffer from soiling and erosion of the leading edge, which can be detrimental for the aerodynamic performance of blade airfoils and, in turn, power capture. The presence of asperities over the blade skin in proximity of the leading edge causes a premature laminar-turbulent transition of the boundary layer leading to a reduction of lift force and an increase in drag. Although the leading-edge erosion is known to have significant effects on wind turbine performance, a model for proactive detection of leading-edge erosion is still missing.

Leading-edge contamination is known to have a significant effect on wind turbine performance; however, automated quantification of the leading-edge contamination is missing. To determine the rotor blade surface condition, a semi-automated contactless measurement method has been developed, which is based on the thermographic determination of the laminar-turbulent transition location. The surface blade is scanned with infrared cameras during normal operations to sense the location of the laminar-turbulent transition. The extent of leading edge contamination is calculated by comparing the natural transition location with the actual transition location influenced by local leading edge surface imperfections.

A quantification of both the extent of the contamination and the impact on wind turbine performance is difficult and calculations are based on estimates. A method for assessing the power loss due to leading edge contamination is proposed for this project. The method is based on thermographic flow measurements along the rotor blade and the automated determination of the laminar-turbulent transition location. A comparison with the expected natural transition of the clean rotor blade position enables the extent of the leading-edge contamination to be quantified. This project includes collection of field data on the degradation of the blade skin due to the leading-edge erosion through infrared (IR) cameras. An experiment was conducted on March 11-12, 2020, at the Cedar Creek wind farm. Turbine blades with different levels of leading-edge erosion were scanned to provide information about the actual location of the laminar-turbulent transition. The IR scans, such as those reported in the figure below, were performed for different incoming wind speed, wind shear and atmospheric stability regimes to cover the broad range of operative conditions of the wind turbines. The experimental IR data will be used to inform XFOIL simulations of the airfoils under examination. The location of the laminar-turbulent transition will be prescribed at the locations observed from the IR data to estimate effects on lift and drag forces. The impact on the annual energy production (AEP) will then be evaluated using a Blade Element Momentum (BEM) model using the modified polar data obtained from XFOIL simulations. The BEM calculations will be coupled with the SCADA data to quantify power losses due to different levels of leading-edge erosion. However, the current analysis of SCADA and meteorological does not show evident impact of LE erosion on the power capture over a duration of three years. The ultimate goal of the project consists in providing an engineering model for proactive detection of the advancement of the leading-edge erosion to predict and avoid the occurrence of significant power losses and support decision-making for economically efficient maintenance of the leading-edge erosion.



Sample of IR image collected at the Cedar Creek wind farm and detection of the laminar/turbulent transition.

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