Ain Shams University

Faculty of Engineering

Mechanical Power Engineering Department

Numerical Modeling of the Erosion and Deposition Processes of Wind Turbine Blades

A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Mechanical Engineering

By

Ahmed Mahmoud Hossam El-Din

Bachelor of Science in Mechanical Power Engineering

Faculty of Engineering, Ain Shams University, 2019

Supervised By

Dr. Aya Diab and Prof. Zakaria Ghoneim

Cairo, 2019

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Date: 26 January, 2019

STATEMENT

This thesis is submitted in partial fulfillment of the requirements for the Masters of Science degree in Renewable Energy, Mechanical Power Engineering Department, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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ABSTRACT

A wind turbine blade can experience performance deterioration due to dust deposition and sand erosion due to the hostile environment of the Saharan regions of the Middle East and North Africa (MENA). This thesis focuses on optimizing the aerodynamic design of the airfoil sections, for lower sensitivity to dust deposition and sand erosion while simultaneously maximizing the annual energy production (AEP). A multi-objective optimization algorithm is developed in MATLAB to modify the profile of six different airfoil sections belonging to DU, NACA and NREL families to achieve high lift-to-drag coefficients ratio with minimum deposition or erosion subject to certain constraints for structural considerations. When the optimized configuration is reached, the aerodynamic performance of the airfoil is tested under particle laden flow using ANSYS-FLUENT computational fluid dynamics software. The results of original profiles indicate that surface roughness led to a drop in the lift-to-drag coefficients ratio by 35% to 65% and 26% to 71% due to deposition and erosion, respectively, over one operational year. On the other hand, the optimized profiles boosted the lift-to-drag coefficients ratio by 11% to 15% and 8% to 27% for deposition and erosion cases, respectively. Concurrently, a drop of 94 to 98% in deposition and 91 to 97% in erosion rates was achieved with an optimized airfoil.

For a more practical application, a case study is undertaken to test the developed model on a 300 kW Nordtank wind turbine operating in Hurghada wind farm in the east coast of Egypt.

To validate the model, the performance of the developed turbine model was compared to that of the chosen wind turbine under clean and dusty conditions. First, a model of the turbine unit was achieved using its generated power curve based on the available technical specifications together with the aid of the Blade Element Momentum (BEM) theory. It is worth noting that in calculating the relative velocity at different sections along the rotor, the shear effect is neglected and a uniform wind speed is assumed.

Under the clean wind conditions, the developed model was in very good agreement with the reported technical data of the wind turbine. Second, the performance of the optimized blade was tested under particle laden flow using ANSYS-FLUENT coupled with MATLAB for the optimization process according to Hurghada wind farm operating conditions. In a particle laden environment, a 10.38% drop in the annual energy production was incurred after an operational period of a 12-month using the original airfoil profiles.

However, with the optimized airfoil sections, a 10.87% boost in the annual energy production was achieved as a result of reducing the deposited rate at the root section by 70%, and raising the lift-to-drag coefficients ratio by 38%. Additionally, the erosion rates for both of mid-span and tip-span sections were decreased by 99% and 93.5% along with a corresponding increase of 9% and 8% in the lift-to-drag coefficients ratio.

Keywords: wind turbine, optimization, annual energy production, genetic algorithm, sand erosion, dust deposition.

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