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Fabrication and Test of an Axial Wind Turbine with the Most Power During Absorbing Flow Kinetic Energy

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ABSTRACT: The aim of the present paper is fabrication and testing an axial wind turbine with power-coefficient greater than 55 percent. Since this power-coefficient is the highest value among the most recent fabricated axial turbines. The present study has led to manufacturing new design of a small wind turbine that has shown power-coefficient of 68 to 80 percent in experimental measurements. Measuring power-coefficient of two-propeller rotor of the wind turbine is in accordance with double-actuator-disc theory, which has proved achievement to power-coefficient of 64 percent. The rotor of the wind turbine consists of an axial three-blade propeller and an optimized six-blade combined-propeller. The parts of the wind turbine have been manufactured with three-dimensional print technology. A large axial fan has been installed horizontally to produce wind flow. A miniature mechanical brake has been installed on the rotor's axis and it is adjustable for generating constant braking torque. The rotor's drag force has been measured with the S-type load-cell that was accommodated in an aerodynamic structure. The small wind turbine has preserved its optimum power-coefficient in the low speed wind flow (in the range 1 to 3 m/sec). Experiment has been accomplished for the rotor of turbine and for the wind turbine having walls and supporting arms and nearly the same results has been achieved.

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Mechanical brake
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1- Introduction

In recent years extensive studies and numerous research projects were published in the field of wind turbines. The extensive research of Blocken [1] in 2014, involves a review on achievements in the field of computational wind engineering during fifty years ago. The research of Blocken describes the progress in the fields of research, executive and educational programs. In 2016 extensive researches were reported for analysis of axial wind turbines. Li et al. [2] presented a new optimization method for increasing overall efficiency of an axial wind turbine with thick airfoil. Their aim was increasing structural strength of blades. They used genetic algorithm for airfoil optimization. They studied flow stability and stall condition after increasing airfoil thickness. In 2016 Belamadi et al. [3] studied the aerodynamics characteristics for slotted blades of wind turbine under stall condition. They employed two-dimensional numerical analysis for determining position of slots. They employed full numerical simulation and illustrated improvement in aerodynamic performance of wind turbine at a range of angle of attack. In 2016, Hassanzadeh et al. [4] optimized chord length and pitch angle distribution for a small wind turbine. Their aim was increasing power absorption of horizontal-axis wind turbines. In 2016 Bai and Wang [5] reported a literature review for computational and experimental methods that were employed for analyzing horizontal axis wind turbines. In 2016, Giahi and Jafarian [6] could investigate the influence of size on aerodynamic characteristics of wind turbine. In 2016 Wang et al. [7] have presented an aero-elastic model for fluid-structure interaction of horizontal-axis wind turbine. Li et al. [8] investigated the influence of optimum pitch angle for blade of wind turbine. They used wind tunnel during their experimental measurements. Their aim was investigating turbulent wake characteristics for horizontal-axis wind turbine. The present paper describes the steps of design, fabrication and test of an axial turbine. The invented turbine absorbs more kinetic energy than existent axial-flow wind turbines. Based on numerical methods and many experiments in the wind flow, the optimum power-coefficient of the optimized proto-type is between 68 and 80 percent. The turbine's rotor consists of an axial three-blade propeller and a mixed six-blade propeller. The supporting arms of the rotor generate a strong structure against vibrational loads. The structure of turbine was designed for minimum loss of turbine's efficiency during fluid-structure interaction. This axial wind turbine is able to extract about 13 to 25 percent more power than conventional three-blade axial wind turbines. Considering geometric similarity the power-coefficient of the invented turbine is higher for increased turbine dimensions.

2- Methodology

2- 1- Design of the wind turbine

Initial design and optimization of the wind turbine was accomplished by programming in MATLAB software. After preparation of the Computer-Aided Design (CAD) geometry a parametric design was performed in SolidWorks software. Each geometric parameter for the propellers was studied numerically and was modified with Computational Fluid Dynamics (CFD) simulation method.

2- 2- Manufacturing of the small-scale wind turbine

Manufacturing of the small-scale wind turbine includes fabrication of a two-stage rotor, casing walls and structure of the supporting arms. The wind turbine has been equipped

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with the electrical and mechanical equipment. A miniature disc-brake was fabricated and installed on the rotor shaft for adjusting holding torque at a constant value.

2- 3- Experiments on the wind turbine

According to Fig. 1, the wind turbine was tested in the high-speed wind flow. The S-type load-cell was employed for measuring drag force of the wind turbine.

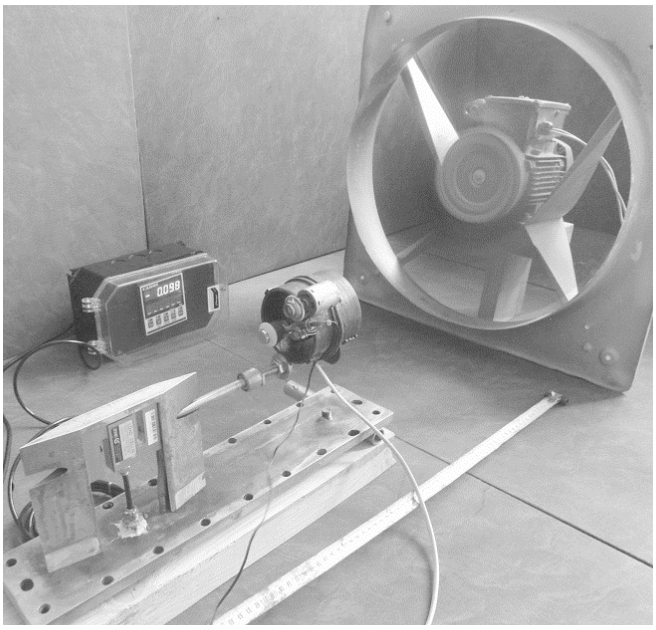

Fig. 1. Experimental setup for test of the wind turbine in the wind flow

3- Results and Discussion

Determining performance characteristics of the small-scale wind turbine in the external wind flow was the most important part of the present study. Many experiments were designed for observing uniform rotation of rotor without contact to casing walls. The wind turbine could resist against drag-force in the high-speed wind flow. For measuring power-coefficient, the braking torque was precisely adjusted at three different values of 0.003, 0.01 and 0.12 N.m. The dimensionless coefficients for evaluating power-coefficient of the wind turbine in the external wind flow were calculated using time-averaged value of external flow velocity, braking torque and angular speed of the two-stage rotor.

Based on linear momentum double-actuator-disc theory, the maximum power-coefficient of the wind turbine with two axial propellers is 16/25. In this base an axial wind turbine with two propellers has maximum power-coefficient of 64 percent. The experimental data of the present paper has illustrated the maximum power-coefficient of 68 to 80 percent. The experimental data have shown at least 4 percent deviation than double actuator-disc theory. The power-coefficient curves of the wind turbine against tip-speed-ratio were plotted in Fig. 2.

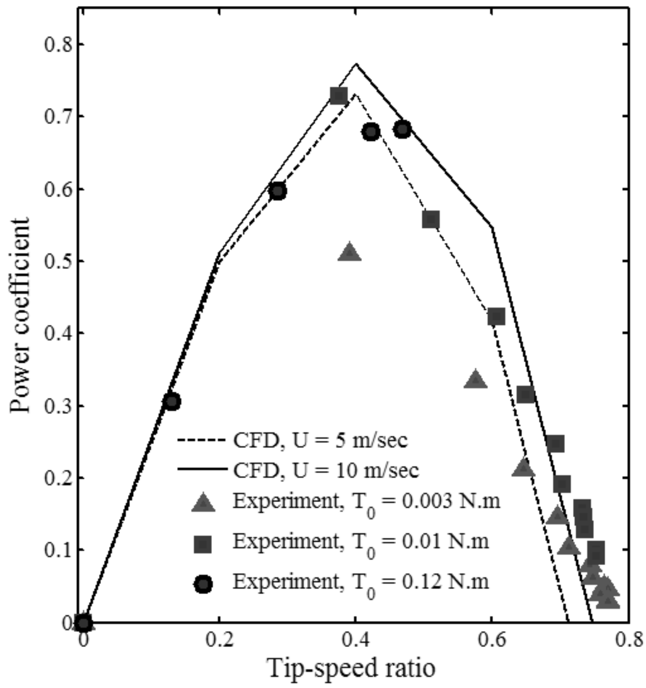

Fig. 2. Experimental and numerical data for power-coefficient of wind turbine against tip-speed ratio

4- Conclusions

The present study described the design and manufacturing of a small wind turbine. Based on numerical simulations it can reach to power-coefficient as high as 80 percent at optimum flow conditions. In the present paper a small-scale wind turbine was tested experimentally. It could illustrate the achievement to optimum power-coefficients in the range of 68 to 80 percent in practice.

The power-coefficient of the two-stage rotor of the wind turbine was nearly in agreement with double-actuator-disc theory. Based on experimental data of the present paper, the optimum power-coefficient of a two-stage axial rotor can exceed 13 to 25 percent than conventional three-blade wind turbines. Design and fabrication of the introduced axial wind turbine with optimized propellers and structural components is a novelty for the wind turbines industry.

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