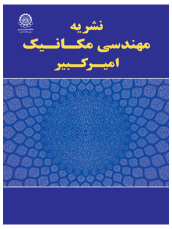

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# Improving the power coefficient of the Darrieus vertical axis wind turbine with the aid of morphing airfoils

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**ABSTRACT:** With the advent of smart materials in recent years, the aviation industry and airfoils have undergone many changes. Research into the use of smart materials in aircraft wings to increase their performance and then the use of smart materials in wind turbine airfoils has begun. In this study, computational fluid dynamics and unsteady Reynolds-Averaged Navier-Stokes equations for a three-bladed Darrieus wind turbine equipped with a morphing airfoil were used to determine the optimum blade cross-section. 250 airfoils were generated by random control points, in Gambit software, they were unstructured and generated as a sliding mesh then they were simulated in 2D Ansys by using pressure-implicit with splitting of operators algorithm. Control points and power coefficient were used for artificial neural network training and the genetic algorithm was used to optimize the power coefficient. In this study, the base airfoil is NACA0015. The results of that have been very effective. For determining the optimal cross-section of the turbine at a full round, the power coefficient of Darrieus wind turbine with the optimal cross-section increased by 42%, and the blade section (airfoil) was also drawn. For determining the optimal cross-section in each of the four zones of the rotor), the most efficient sections (airfoils) in four-zone were obtained, increasing the turbine power coefficient by 60% was the result of this optimization.

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## 1. Introduction

The field of morphing wings has attracted the attention of many research groups in the last century and a lot of research has been done in this field, with all this effort, the commercial product has not been made with morphing wings in the low speed range. However, there are designs for small, low-speed wings and aircraft, or even tested in wind tunnels, but very few prototypes have been made and tested. The growth of science and the unique specifics of smart materials has helped to the improvement of morphing airfoils and aircraft at low speeds and solved its challenges [1].

Macphee and Beyene[2] experimentally investigated the power coefficient of wind turbine with morphing airfoil. Their results showed that power coefficient increased by 42%. Fincham and Friswell [3] increased the efficiency of the airfoil by assuming the morphing airfoil chamber. Their results showed that drag force decreased by 30 to 60%. Tay and Lim [4] examined numerically the morphing airfoil based on NACA 0012 in the chord direction to increase the lift force and its propulsion. Mohammad et al. [5] investigated numerically Darrieus wind turbine for 25 different airfoils by URANS method. Their results presented that the power coefficient of the turbine with LS (1)-0413 airfoil in comparison to NACA0021 airfoil increased by 16%. Mohammad et al. studied [6] numerically modeled the Darrieus wind turbine using a slotted airfoil using the URANS method. The K-ε Realize turbulence model is also used in two-dimensional simulation. Their results evaluated in different tip speed ratios. The power coefficient of the wind turbine in the tip speed ratio of 3 for the slotted airfoil in comparison to NACA0018, increased by 54%. The purpose of this study is to present a conceptual optimization method to increase the efficiency and power production of the wind turbine under optimal operating conditions and constant solidity by the morphing airfoil blades. The innovation of this research compared to previous researches is the simultaneous use of artificial neural networks and genetic algorithms for optimization, which significantly reduced the simulation time and significantly increased the power coefficient of Darrieus wind turbine.

## 2. Aerodynamic of Darrieus Wind Turbine

Darrieus wind turbine blades are designed to have proper aerodynamic performance in any cycle that experiences different angles of attack. Due to the angle of attack of the airfoil, lift and drag forces acting on the airfoil can be decomposed into two tangential and normal components. These two components are tangential and normal to the airfoil at any moment. Tangential force produces the torque required to produce power in the wind turbine, which is obtained from the difference between the projection of the lift and drag forces on the airfoil [7].

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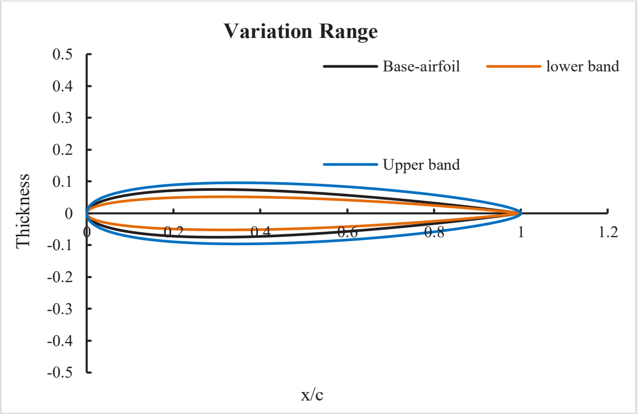

**Fig. 1. Upper and lower bonds of airfoil variations**

The following equations show the procedure of calculating the power coefficient of wind turbine of lift and drag force, respectively [8]:

$$F_t = L\sin\alpha - D\cos\alpha \tag{1}$$

$$F_n = L\cos\alpha + D\sin\alpha \tag{2}$$

$$F_{ta} = \frac{1}{2\pi}\int_0^{2\pi} F_t(\theta)\,d\theta \tag{3}$$

$$Q = NF_{ta}R \tag{4}$$

$$P = Q \times \omega \tag{5}$$

$$C_p = \frac{P}{P_{air}} = \frac{P}{\frac{1}{2}\rho A V_\infty^3} \tag{6}$$

where, $L$ is the lift force, $D$ is the darg force, $N$ is the number of blades, $R$ is the rotor radius, $P$ is the power of wind turbine and $C_p$ is the power coefficient of wind turbine.

## 3. Computational Setup

Optimization of airfoil of the wind turbine as an input variable requires a function to produce a smooth and continuous surface for the airfoil. The morphing airfoil variates in the direction of the airfoil thickness by 30% of the total thickness of the airfoil. For each of the airfoil surfaces, 5 points were selected as control points to produce the airfoil surface. Two control points are located at the leading and trailing edge of the airfoil, and 3 points create the main variations in the shape of the airfoil. Fig. 1 shows the variation range of upper and lower bonds of the morphing airfoils.

## 4. Optimization

First, the control points that produce the shape of the airfoils are generated by the Bezier curve in MATLAB and then sent to Gambit to draw the airfoil and its meshing, in the next step, airfoils are sent to Ansys software for simulation. The outputs of Ansys, which are the power coefficient are sent to the artificial neural network in MATLAB along with the control points to be trained in the artificial neural network. After training the artificial neural network, it is given to the genetic algorithm as a function so that the maximum power coefficient and control points related to it, can be reported as the output of the genetic algorithm to increase the power coefficient of the wind turbine.

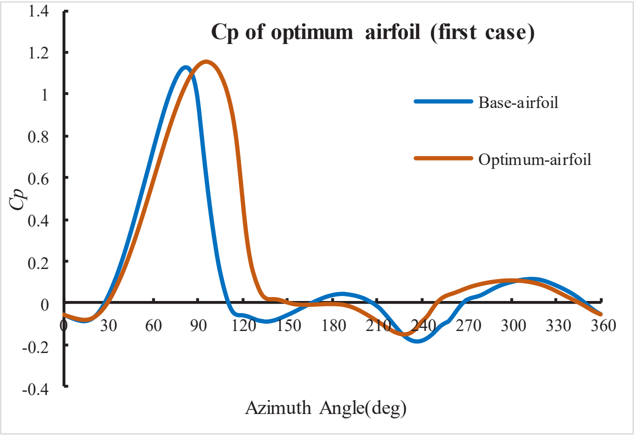

**Fig. 2. Diagram of power coefficient for one blade with new and base airfoil**

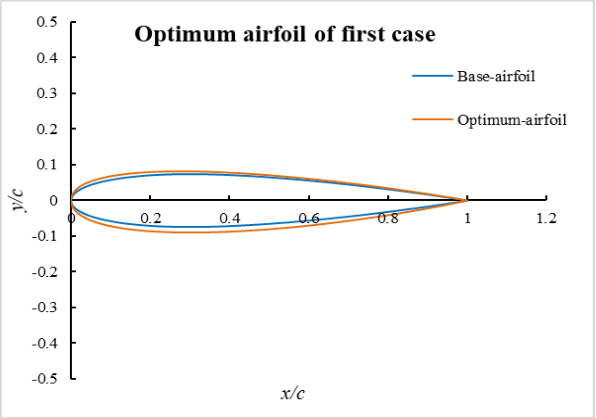

**Fig. 3. New (optimum) airfoil and base airfoil**

## 5. Results

In the first case, the optimum airfoil of Darrieus wind turbine is obtained in its optimal condition ($TSR = 1.5$), which is uniquely cross-sectional for airfoil blades in each rotation of the turbine. The results show power coefficient of wind turbine with the new airfoil increased by 42% in comparison to base airfoil. Fig. 2 shows the power coefficient diagram in the rotor rotation angle for a blade. Fig. 3 shows the optimum airfoil in each turbine rotation with the base airfoil.

## 6. Conlcusions

Artificial neural networks have a high ability to learn nonlinear problems and with proper training of artificial neural networks, in addition to accurately predicting the parameters, optimization operations can be performed more quickly. With the use of morphing airfoils, the performance of systems such as wind turbines and aircraft wings can be significantly controlled. According to the results, the power coefficient of the wind turbine for the first and second case in comparison to based airfoil increased by 42% and 60%, respectively.

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