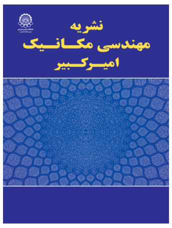

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Power Improvement of a Commercial Large Scale Vertical-Axis Wind Turbine Using Plasma Actuators

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ABSTRACT: The present study numerically investigates the feasibility of using multiple dielectric barrier discharge plasma actuators inside the surface of geometry as a novel approach for active flow control over a large vertical axis wind turbine. For this reason, the plasma actuator is modeled based on Suzen model and the results are validated. Then, a computational study is carried out on a commercial large scale vertical -axis wind turbine to examine the effect of the presence of the plasma actuator. The 530 G vertical-axis wind turbine is used as the baseline case. The plasma actuator was applied inside the surface of the blades of turbine and on all their surfaces in a sequential and simultaneous way. It is revealed that the use of multiple dielectric barrier discharge actuators could enhance the induced velocity; this affects the pressure distribution and increases the aerodynamic torque. Consequently, an averaged power increase of 3 % was achieved. Possibility of increase in wind turbine power even in a commercial scale large turbine has been proved by flow separation control using the plasma actuation technology. In addition, the application of the plasma inside the surface of the blades will not effect on its performance.

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1. Introduction

In recent years wind turbines have become the symbol of clean and green energy. In fact, unlike most other technologies for generating electricity, wind turbines do not utilize combustion processes that yield environmentally hazardous emissions [1]. As wind energy forces to reduce the cost of energy, manufacturers have sought to increase the size and capacity of wind turbines. Increasing the generated power of a wind turbine by low construction costs is an important goal in the recent renewable energy literature [2].

In the present study, the vertical–axis wind turbine of 530 G [3] that is a commercial large scale of vertical wind turbine is numerically simulated. Its blade is equipped with multiple Dielectric Barrier Discharge (multi-DBD) plasma actuators for active flow control to improve its aerodynamic performance. Multi-DBD plasma actuators are usually composed of several single DBD in series in order to cumulate the induced velocity produced by each actuator. According to the literature, most studies on the effects of plasma actuators on performance of wind turbine are based on horizontal-axis wind turbine blades e.g., [4-5] or experimentally on small scale of vertical-axis wind turbines [6]. The main contribution of this study is to considering the effects of the plasma actuator on performance of large scale of vertical-axis wind turbine numerically. In addition, application of the multi-DBD plasma actuator on Vertical Axis Wind Turbines (VAWT) numerically has not been studied before, and we will show here it is vital for turbine performance improvement.

2. Baseline Wind Turbine

The vertical axis wind turbine 530 G [3] was chosen as the reference model for this study. The specifications of this turbine are given in Table 1.

3. Numerical Solution

3.1. Vertical-axis wind turbine

For numerical simulation of the flow around the VAWT, the flow is simulated in 2 Dimensional (2D) and 3D. To solve the flow field and simulate rotor motion, Moving Reference Frame (MRF) method has been implemented. In fact, to apply the turbine rotation, the steady mode of MRF is used as the initial answer, and then the dynamic mesh model is used for unsteady mode. In this method, the numerical domain is divided to an inner cylinder sector having a diameter of

Table 1. Specifications

Specifications	
Number of blades/set	4
Rotor diameter	5.385816 m
Blade length	3 m
Blade cord	0.44704 m
Rotor RPM	80

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about 1.05 R and the turbine sections are inside it, and the exterior boundary. The boundary between these two sectors is separated by the interface zone. The exterior boundary is stationary but interior boundary and inner mesh with blades that are inside it can rotate with respect to the non-moving area during numerical simulations. In other words, for all the simulations, two different grid levels have been adopted: a fixed sub-grid with the external dimensions of the flow domain, and a dynamic sub-grid that includes the VAWT geometry and allows a relative motion with respect to the fixed grid.

During a solution after a steady solution and a suitable initial solution, the problem is solved unsteady and after an initial time, the results are repeated for each blade during the rotation period, and integration can be done on it. Also, two of the most referenced turbulence models for cases including strong adverse pressure gradients, k-ϵ Realizable and k-ω SST are have been selected and adopted in the Computational Fluid Dynamics (CFD) modeling approach. The 2D mesh adopted is a structured mesh and y+ values of the near- wall is around 1 so that more accurate answers can be obtained. A structured grid with higher concentration has been established. Cells concentrations in the proximity of wall and blade surface are selected in a way that boundary layer and flow physics at these regions is captured with approvable accuracy. As you move away from airfoil, for simplicity, a triangular unstructured mesh has been used.

The pressure-velocity coupling scheme in the solver is chosen simple. Pressure discretization is presto. In addition, momentum discretization, turbulent kinetic energy discretization and specific dissipation rate discretization are chosen second order upwind.

3.2. Plasma actuator

3.2.1. Governing equation

$$\vec{f}_B = \rho_c \vec{E} \tag{1}$$

$$\vec{E} = -\nabla \Phi \tag{2}$$

$$\nabla.(\varepsilon \vec{E}) = \rho_c \tag{3}$$

$$\frac{\partial \vec{U}}{\partial t} + \nabla.(\vec{U}\vec{U}) - \nabla.(\nu \nabla \vec{U}) = -\frac{1}{\rho}(\nabla P - \vec{f}_B) \tag{4}$$

Governing equations are:

where $\vec{f}_B$, ρ_c, $\vec{E}$, Φ, ε, $\vec{U}$ and P are the body force vector, net charge density, electric field, total electric potential, permittivity, velocity vector and pressure respectively. In order to imply the plasma actuator, we develop a User-Defined Function (UDF) in Fluent software.

4. Discussion and Results

Fig. 1 shows total electric potential on blade surface. As it is obvious, 8 actuators have been placed on entire surface of the blade (inboard and outboard simultaneously). In current study multiple actuators based on Suzen et al. [7] model is used to increase the total induced body force. The width of all the electrodes is 10 mm and their thickness is 0.1 mm.

The k-ε Realizable method is used to solve flow field of the wind turbine. Fig. 2 illustrates the torque variation versus time with and without plasma actuator. Also, Fig. 3 shows the torque variation versus azimuthal angle with and without plasma actuator. As it is obvious from these figures, presence of the plasma actuators has increased the torque and if we integrate graphs against time, it shows the wind turbine output power increased by 3%.

5. Conclusions

In the current study, application of plasma actuator as device for active flow control over the commercial large-scale vertical-axis wind turbine 530 G has been considered.

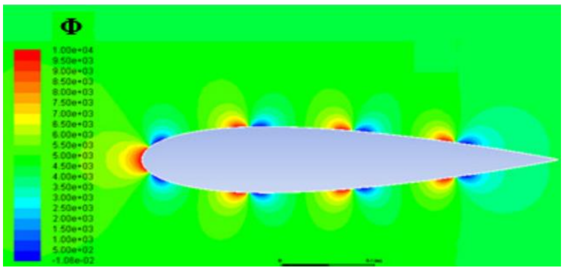

Fig. 1. Tota electric potential

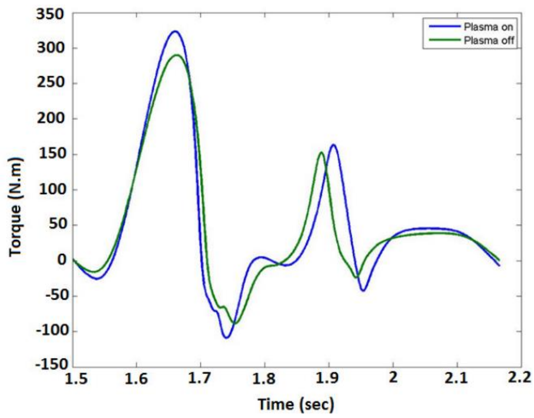

Fig. 2. Torque variation vs. time with and without plasma actuator

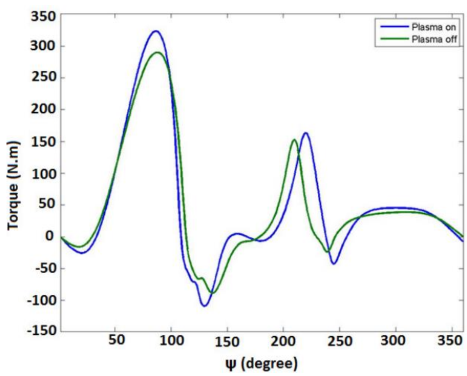

Fig. 3. Torque variation vs. azimuthal angle with and without plasma actuator

Also, its effect on the wind turbine power was examined. In this reason, multiple plasma actuators were located on the entire surface of the blade. The results revealed that this configuration could significantly increase plasma effects. Eventually, a power increase of 3% was obtained. Finally, Power enhancement even in a commercial large–scale vertical-axis wind turbine has been demonstrated by using the multiple plasma actuators.

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