EFFECT OF DIELECTRIC BARRIER DISCHARGE (DBD) PLASMA ACTUATOR ON WIND TURBINE BLADE

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This report is submitted
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DECLARATION

I declare that this project report entitled "Effect of Dielectric Barrier Discharge (DBD) Plasma Actuator on Wind Turbine Blade" is the result of my own research except as cited in the references.

Signature :...................................

Name :...................................

Date :...................................

SUPERVISOR DECLARATION

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree in Bachelor of Mechanical Engineering (Hons).

Signature :..................................

Supervisor Name :..................................

Date :..................................

DEDICATION

In the name of Allah, the Most Gracious and the Most Merciful

I dedicate this work to:

My parents,

Ramli Bin Yusof and Salmiah Binti Saidin

My siblings,

Supervisor who always give support and encouragement,

Dr. Nazri bin Md Daud

ABSTRACT

Dielectric barrier discharge (DBD) plasma actuator are electrical devices that generate a wall bounded jet without the use of any moving parts, rapid response for feedback control and low mass. DBD plasma actuator was also currently considered as popular actuator for aerodynamic flow control devices. The NACA 4415 airfoil of aerodynamics are mainly used as a wind turbine blades profile. This study deals with the enhancement of aerodynamic performance on NACA 4415 airfoil when a DBD plasma actuator is mounted near upper surface of leading edge and middle span of an airfoil. The experimental was conducted with the objectives that have been set which is to evaluates the lift coefficient, C_L and drag coefficient, C_D of wind turbine blade for base case (without plasma) and actuation mode (with plasma) and then correlate these coefficients between both cases. Wind tunnel test have been conducted to collect a data for lift and drag force with velocity 15 m/s and 20 m/s which to investigate the effectiveness of DBD plasma actuator. The DBD plasma actuator consists of two copper tape electrodes separately disposed on the top (exposed electrode) and below (encapsulated electrode) a dielectric material with 5 mm width and 50 μm thick that arranged parallel with 1 mm gap overlap. The anode and cathode electrodes were separated by attached a 100 μm thick Kapton film layer, which acts as a dielectric barrier material. From the result analysis, the actuation mode was able to increase C_L in average 1.7 % for 15 m/s and 2.1 % for 20 m/s for plasma actuator mounted at leading edge of airfoil. While for plasma actuator mounted at middle span of airfoil, the actuation mode was able to improve the percentage of C_L in average 0.6 % for 15 m/s and 0.8 % for 20 m/s. Furthermore, the result analysis for C_D showed that the actuation mode was able reduce C_D in average 5.6 % for 15 m/s and 3.5 % for 20 m/s for plasma actuator mounted at leading edge of airfoil. While the actuation mode for plasma actuator mounted at middle span of airfoil was also showed able to reduce C_D in average 1.8 % for 15 m/s and 1.0 % for 20 m/s. These result showed that the actuation mode was able to increase the aerodynamic performance of an airfoil by increasing C_L while reducing the C_D compared to base case. Therefore, the efficiency of the aerodynamic geometry can be increased with the presence of DBD plasma actuator.

ABSTRAK

Dielektrik halangan pelepasan (DBD) penggerak plasma adalah alat peranti elektrik yang menjana jet dinding yang sempit tanpa menggunakan mana-mana bahagian yang bergerak, tindak balas pantas untuk kawalan suap balik dan mempunyai jisim yang rendah. DBD halangan penggerak plasma juga pada masa ini dianggap sebagai penggerak yang popular bagi alat peranti kawalan aliran aerodinamik. NACA 4415 kerajang udara yang aerodinamik kerap digunakan sebagai profil bilah turbin angin. Kajian ini membincangkan berkenaan peningkatan prestasi aerodinamik pada NACA 4415 kerajang udara apabila DBD halangan penggerak plasma dipasang di bahagian atas permukaan pinggiran hadapan dan rentang pertengahan kerajang udara. Eksperimen dijalankan dengan objektif yang telah ditetapkan untuk menilai pekali angkat, C_L dan pekali seretan, C_D bilah turbin angin untuk kes asas (tanpa plasma) dan mod penjanaan (dengan plasma) dan kemudian hubung kaitkan pekali antara kedua-dua kes. Ujian terowong angin telah dijalankan bagi mengumpul data daya angkat dan seret dengan halaju 15 m/s dan 20 m/s untuk mengkaji keberkesanan DBD halangan penggerak plasma. DBD halangan penggerak plasma terdiri daripada dua elektrod pita tembaga yang dipasang secara berasingan di bahagian atas (elektrod terdedah) dan di bawah (elektrod terkurung) bahan dielektrik dengan lebar 5 mm dan tebal 50 µm yang disusun selari dengan jarak 1 mm bertindih. Elektrod anod dan katod dipisahkan dengan melampirkan lapisan filem Kapton tebal 100 µm, yang berfungsi sebagai bahan halangan dielektrik. Melalui dari hasil analisis, mod penjanaan dapat meningkatkan C_L pada purata 1.7 % untuk 15 m/s dan 2.1 % untuk 20 m/s untuk penggerak plasma yang dipasang di pinggiran hadapan kerajang udara. Sementara itu, bagi penggerak plasma yang dipasang pada jarak rentang pertengahan kerajang udara, mod penjanaan mampu meningkatkan peratusan C_L secara purata 0.6 % untuk 15 m/s dan 0.8 % untuk 20 m/s. Tambahan pula, hasil analisis untuk C_D menunjukkan bahawa mod penjanaan dapat mengurangkan C_D pada purata 5.6 % untuk 15 m/s dan 3.5 % untuk 20 m/s untuk penggerak plasma dipasang pada di pinggiran hadapan kerajang udara. Sementara itu bagi mod penjanaan untuk penggerak plasma dipasang pada jarak rentang pertengahan kerajang udara juga dapat mengurangkan C_D secara purata 1.8 % untuk 15 m/s dan 1.0 % untuk 20 m/s. Hasil ini menunjukkan bahawa mod penjanaan dapat meningkatkan prestasi aerodinamik kerajang udara dengan meningkatkan C_L dan mengurangkan C_D berbanding dengan kes asas. Oleh itu, kecekapan geometri aerodinamik boleh ditingkatkan dengan kehadiran DBD halangan penggerak plasma.

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LIST OF ABBREVIATIONS

AC	Alternating Current
AOA	Angle of Attack
DBD	Dielectric Barrier Discharge
DC	Direct Current
NACA	National Advisory Committee Aeronautics
VAWT	Vertical Axis Wind Turbine
3D	Three Dimension

LIST OF SYMBOL

C_L	=	Lift Coefficient
C_D	=	Drag Coefficient
D	=	Drag Force
L	=	Lift Force
ρ	=	Density
Re	=	Reynolds Number
U	=	Velocity
v	=	Wind Velocity
x	=	Displacement

CHAPTER 1

INTRODUCTION

1.1 Overview

In this chapter, introduction for this project will be discuss in detail which contains background information about effect of Dielectric Barrier Discharge (DBD) on wind turbine blade, problem statement, objective and the scopes of projects.

1.2 Background of Study

Langmuir in 1982 was discovered the term plasma which can identify the fourth state of matter consisting in an ionized gas (J. Vernet, 2014). Langmuir discriminate the matter as containing a much equal number of ions and electrons and from here being nearly zero space charged. Langmuir also considered about a medium thus entraining ions, electrons and more neutral atoms and the blood plasma which is the fluid entraining the blood cells. Nowadays the analogy cannot be made anymore as it was discovered that there is no entraining medium, but the phrase plasma still can be used.

First researchers who investigated about plasma actuator is Roth et al. (2000). Since then, these actuators also have been used for application of the control of leading edge boundary layer separation to make airfoil lift at constant high angles of attack and enhance lift at low and moderate angles of attack by adding momentum in the direction of the incoming flow. Roth et al. (2000) show that the power that could be produced by the plasma actuator during natural flow.

There are many kinds of techniques currently used for wind turbine power control. Some technique that becomes a common device in the application of control natural flow is Dielectric Barrier Discharge (DBD) plasma actuators. The main objective of plasma actuators is to control separation by reattaching a naturally detached airflow or by detaching a naturally attached airflow. The most common variety of plasma actuators, is an electro-fluidic device which consists of two thin electrodes arranged asymmetrically and parallel to each other, one electrode exposed to the air and the other one offset axially and fully hidden beneath a layer of dielectric material (Enloe et al., 2004).

Dielectric barrier discharge (DBD) has been demonstrated in a range of applications involving separation control, lift enhancement, drag reduction and flight control without moving surfaces. For this project, it will be only focuses on performance of wind turbine blade in term of lift coefficient, C_L and drag coefficient, C_D. The majority of the previous study in plasma actuation has been limited to low and moderate Reynolds numbers. Thomas et al. (2008), shows that the results which he obtained from plasma actuation as a way to streamline the flow past a cylindrical bluff body and to regulate noise.

Besides that, to the experimental use of the plasma actuators, models for the space-time transformation of the plasma generation over the actuator, and a first-principle formulation for the body force produced by the plasma on the ambient flow, have been implemented in numerical flow solvers (Bell G., 2014). These have produced first class agreement with experiments on leading edge separation control in both steady and unsteady cases. Their purpose is to produce simulations that can be used in optimizing the design and placement of plasma actuators for different applications of flow control, for example such as wind turbine blades that need to enhance aerodynamic performance.

The performance of DBD plasma actuators on vertical axis wind turbines (VAWT) has been earlier researched (D. Greenblatt et al., 2012). An experimental study was performed on a small scale VAWT employing aluminum NACA 0015 airfoils and DBD plasma actuators connected on the leading edge of the blades. With actuation occurring only during the upstream half of the azimuth angle, power growth of up to 38% was measured. Most importantly, it was concluded that when up-scaling the turbine size by a factor of 10, the SDBD power requirements to achieve equivalent effect were only 1.7% (D. Greenblatt et al., 2012).

The above applications and some others have already been discussed in detail. The plasma actuators can be made flush with the suction surface of the wind turbine blade, thus presenting a practically non-intrusive approach to modify the effective aerodynamic shape of the wind turbine profile via the body force. The technology of plasma actuation has evolved substantially over the past few years. The further research in wind turbine aerodynamics and control will require active control technology to build a "smart" turbine blade.

1.3 Problem Statement

One of the major issues for the future of humanity is guaranteeing the continuation of energy supply. A future that depends on renewable energy will prove the future generations. Wind energy, in the form of modern wind turbines is definitely one of the technologies recommended. During strong winds, the turbine should not exceed its maximum design output to keep away from risking mechanical failure. Therefore, a stable and economical technology to control the wind turbine power is needed to enable a more widespread use of this clean energy source.

Furthermore, there are some of the literature related wind tunnel testing of wind turbine systems involves experiments to determine the lift and drag coefficients of airfoil cross-sections that will be used in wind turbine blade design. The wind tunnel also is capable of performing aerodynamic test of various objects where the basic principle theory of aerodynamics. In the beginning, the NACA airfoil sections were used as an experimental for wind turbines blade such as the NACA 4415 airfoil. These airfoils were considered ideal because of their laminar flow characteristics (Hau, E., 2006).

Besides that, this airfoils also have been tested in the variable density wind tunnel which is use the method of geometric characteristics. For wind turbines, it is desired to maximize lift and minimize drag for the chosen design speed. So more research is needed to improve performance and further examine the aerodynamic behavior of the wind turbine blades.

In general, DBD plasma actuators were used to improve the performance on vehicle like a car, truck and wing airplane. The basic question addressed in this work is whether plasma actuation is, by itself, capable of limiting the power of wind turbine blade. So, this research proposes the technology of DBD plasma actuation as a viable solution to improve the performance of wind turbine blade in terms of lift coefficient, C_L and drag coefficient, C_D that is free from a lot of the practical restrictions, mechanical and economical.

1.4 Objectives

The main objectives of this project are:

1) To evaluate the lift coefficient, C_L and drag coefficient, C_D of wind turbine blade for base case and actuation mode.
2) To correlate the lift coefficient, C_L and drag coefficient, C_D between base case and actuation mode.

1.5 Scope of Project

In this project, the scope will be:

1) Model airfoil NACA 4415
2) Dielectric Barrier Discharge (DBD) plasma actuator with power at 6 kV and frequency at 8 kHz

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The main purpose of this literature review is to get information about the project from the reference books, magazines, journals, technical papers and web sites. In this chapter the fundamental of the techniques will discussed in detail and the discussion will be made base on all the sources.

2.2 Wind Turbine Flow Control

Wind energy, as other type of renewable sources of energy like solar and tidal, is showing a moment of great evolution and expansion. For these reasons sustainable energy technologies have emerged, the belief for the development of these technologies become more dominant. These energy sources are nearly inexhaustible, their use causes no pollution to the environment and they moderately contribute to the reduction of reliance on conventional energy source.

Generally, to harvest more energy from the wind is by increasing the rotor diameter of modern wind turbines, wind turbine manufacturers seek to actualize procedures that reduce blade load fluctuations and structural vibration (Victor and Soham, 2018). The use of variable-speed and individual blade pitch control rotors offers an efficiency increase by allowing the turbine to operate closer to its maximum aerodynamic performance at a wider range of wind speeds, thus extracting more energy from the wind (Victor and Soham, 2018). Figure 2.1 shows the primary subparts of a wind turbine.

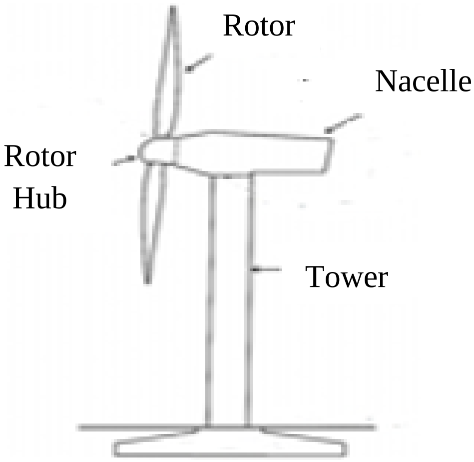

Figure 2.1: Primary subparts of a horizontal axis wind turbine (Choudhry A., 2015).

The phrase flow control will be linked with any device or method that modifies a given flow field. Such amendment of the flow could be desirable to get a kind of reasons, ranging from enhancement of lift to augmentation of mixing. In some cases, flow control employed for a particular benefit may also entail one or more undesirable effects on other properties of the flow. In these cases, a trade-off has to be made based on judgment. Depending on the flow control nature, devices can be classified under 2 categories which is actives control and passives control as shown in Figure 2.2.