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Research Paper

STUDY ON WIND TURBINE AND ITS AERODYNAMIC PERFORMANCE

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This paper aims to present the Study on wind turbine and its aerodynamic performance. Rapid increase in global energy requirements has resulted in considerable attention towards energy generation from the renewable energy sources. In order to meet renewable energy targets, harnessing energy from all available resources including those from urban environment is required. This paper represents the study of wind turbine. There are two type of wind turbine Vertical axis wind turbine and Horizontal axis wind turbine that had been discussed on this paper. Vertical Axis Wind Turbines (VAWTs) are seen as a potential way of utilizing urban energy sources. Most of the research on the wind turbines constitutes condition monitoring and performance optimization of VAWTs under a constant velocity of air where the transient effects have not been accounted. The inconsistent behavior of the wind may change the nature of the flow field around the VAWT which could decrease its life cycle. This study is an attempt to use Computational Fluid Dynamics techniques to study and analyses the performance of a wind turbine under accelerating and decelerating air inlet velocity. A Horizontal-Axis Wind Turbine (HAWT) blade with 10,000 Watt power output has been designed by the Blade Element Momentum (BEM) theory and the modified stall model, and the blade aerodynamics are also simulated to investigate its flow structures and aerodynamic characteristics.

Keywords: Vertical axis wind turbine, Horizontal-axis wind turbine, Reynold number

INTRODUCTION

Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. The terms wind energy or wind power describes the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity

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(Hsiao *et al.*, 2013). In general, the sectional shape of the Horizontal-Axis Wind Turbine (HAWT) blade consists of the two dimensional (2D) airfoils, which result the lift and drag forces by virtue of pressure differences across the 2D airfoil. Because of this, the Blade Element Momentum (BEM) theory is widely used to outline a procedure for the aerodynamic design of a HAWT blade. The optimum distributions of the chord length and the pitch angle in each section can be acquired according to the design parameters, which include the rated wind speed, number of blades, design tip speed ratio and design angle of attack (Manwell *et al.*, 2009; Bai and Hsiao, 2010; and Hsiao and Bai, 2013). The performance capabilities of the wind turbines depend greatly on the torque output which further depends upon the torque generating capability of the rotor. HAWT are more efficient as compared to VAWT but require good quality wind energy. In urban areas where wind is in-consistent and highly fluctuating, VAWT is more beneficial due to its low starting torque characteristics as well as other advantages like being in-expensive to build and of simple design (Rohatgi and Barbezier, 1999; Manwell *et al.*, 2009; and Park *et al.*, 2012). Wind energy has become one of the fastest growing renewable energy sources, because energy generated by wind power is one of the cleanest energy resources available. As Horizontal-Axis Wind Turbine (HAWT) blades become lighter and more flexible, the system dynamics must be analyzed comprehensively in order to evaluate and understand the complex interaction of the elastic vibrations of the wind turbines and the unsteady aerodynamic forces acting on them. In line with the demand for lighter wind turbine blades, new advanced fabrication methods and composite materials have been introduced, and this has resulted in reduced structural damping, which is a property that until very recently was impossible to model and enhance (Riziotis *et al.*, 2004).

TYPES OF WIND TURBINE

Horizontal-Axis Wind Turbine (HAWT)

Horizontal-Axis Wind Turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

Figure 1: Horizontal-Axis Wind Turbine

Vertical Axis Wind Turbines (VAWTs)

Vertical axis wind turbines are a type of turbine where the main rotor shaft runs vertically. These turbines can rotate unidirectional even with bi-directional fluid flow. VAWT is mainly due to the advantages of this kind of machine over the horizontal axis type, such as their simple construction, the lack of necessity of over speed control, the acceptance of wind from any direction of the mechanical design limitations due to the control systems and the electric generators are set up statically on the ground. Generally, there have been two distinct types of vertical axis wind turbine that is the Darrieus and savonius types. For the Darrieus, there are three common blades that are Squirrel Cage Darrieus, H-Darrieus and Egg Beater Darrieus (David and Spera, 1998).

Figure 2: Vertical Axis Wind Turbine

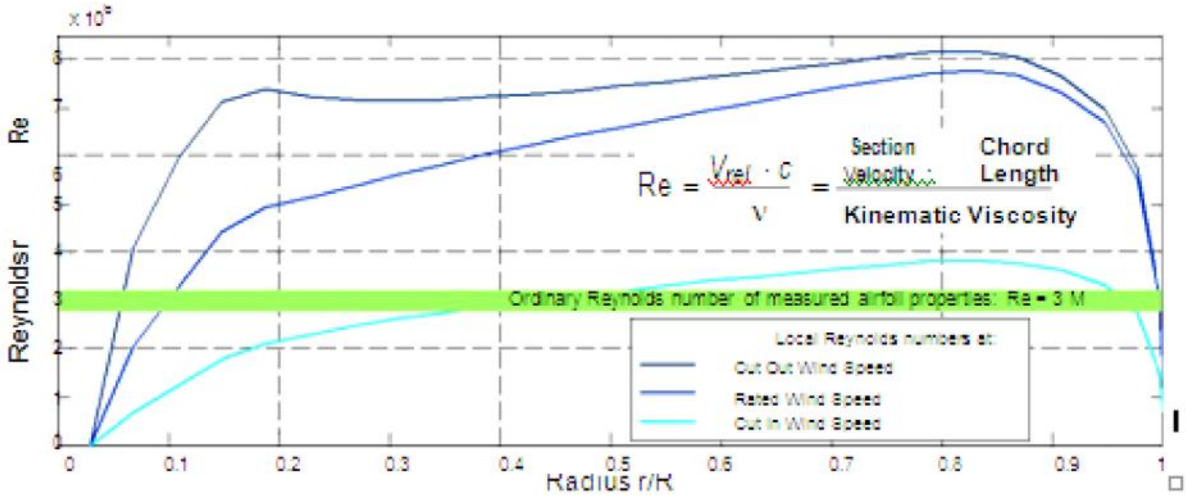
EFFECT OF REYNOLD NUMBER

For axial-flow (commonly referred to as horizontal-axis) turbines, small changes in angle of attack a of the local relative wind w.r.t. blade chord occur throughout blade rotation, and are due to mean shear in the boundary layer (which can also cause varying deformation) or turbulence. This means it's relatively easy to predict turbine performance with models that employ static foil section data, e.g., Blade Element Momentum (BEM) methods.

Reynolds Number Effects on Wind Turbines

1. The maximum power coefficient CP.max is increased. This is caused by a lower drag

Figure 3: Local Reynolds Number on the Reference Rotor Blade EU100 at Various Operating Conditions. The Local Reynolds Number Only Depends on the Section Velocity, Vrel and the Respective Chord Length, c at Constant Kinematic Viscosity, ¬



in the low drag bucket, which leads to less profile losses and thus a power coefficient which is closer to the theoretical maximum of CP = 0.59.

2. The power coefficient at low tip speed ratios is increased. The reason therefore is that more lift can be generated due to the higher maximum lift caused by the Reynolds number effect. Also less blade sections operate in stalled conditions which results in less drag. Hence profile losses are decreased at low tip speed ratios as well.
3. The shape of the power coefficient curve changes, its saddle becomes wider. This is a consequence of 1. And 2: less drag at the Best lift to drag ratio and higher stall angle of attack. This is Advantageous for operating conditions at non optimum tip speed Ratios, i.e., for operation at maximum tip speed below rated power.
4. The optimum blade set angle is increased. The reason therefore is that the best lift to drag ratio is shifted to smaller angles of attack and thus smaller lift coefficients. Hence the optimum performance is reached at smaller section in flow angles which is achieved by increasing the pitch.
5. The optimum tip speed ratio is increased. The reason therefore is that the optimum lift to drag ratio occurs at smaller angles of attack and hence at smaller lift coefficients. The decrease in lift coefficient is compensated by increasing the section velocity, which shifts the optimum tip speed ratio to higher values.
6. The thrust coefficient is increased at low tip speed ratios, but can be partly decreased by increasing the blade set angle (Abbott Ira *et al.*, 1945).

Reynolds Number Effect of Contaminated Profile

Figure 4 shows the Reynolds number effect on the lift coefficient. With increased Reynolds

Figure 4: The Effect of Carborundum 60 on the Lift Curve at Various Reynolds Numbers

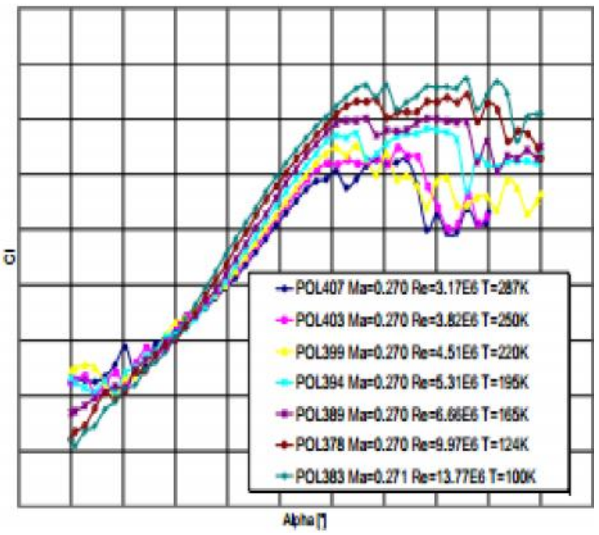
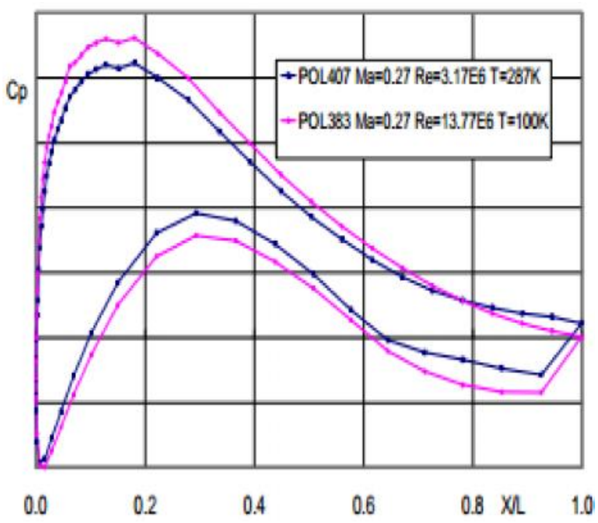


Figure 5: The Effect of Carborundum 60 on the Pressure Distribution at Two Reynolds Numbers



numbers the boundary layer becomes thinner, but more powerful. The impact of carborundum thus decreases. The stall occurs at higher angle of attack, so climax increases.

Reynolds Number Effect of Clean Profile

For the clean thin profile the Reynolds number effect is typical, just like the description in the classical literature. As shown in Figures 6 and 7, with increased Reynolds number, Clmaxincreases, lift curve is more linear, its slope goes up slightly, Cdmindecreases and the laminar bucket becomes smaller. Figure 10a is a schematic of a straight-bladed-fixed-pitch VAWT which is the simplest, but typical form, of the Darrieus type VAWTs. Figure 10b illustrates typical flow velocities around a rotating VAWT blade at a given azimuthal angle ¯, as well as the aerodynamic forces perceived by the blade. The azimuthal angle ¯ is set to be zero when the blade is at the top of the flight path and is increases in a counter-clockwise direction.

Figure 6: Reynolds Number Effect on Lift for Clean Profile

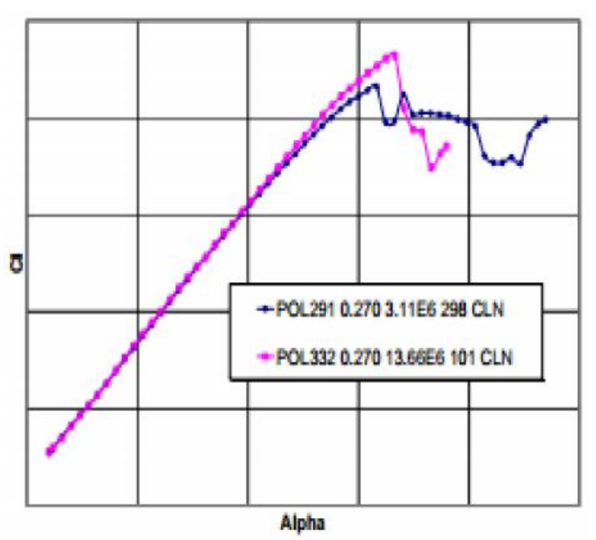
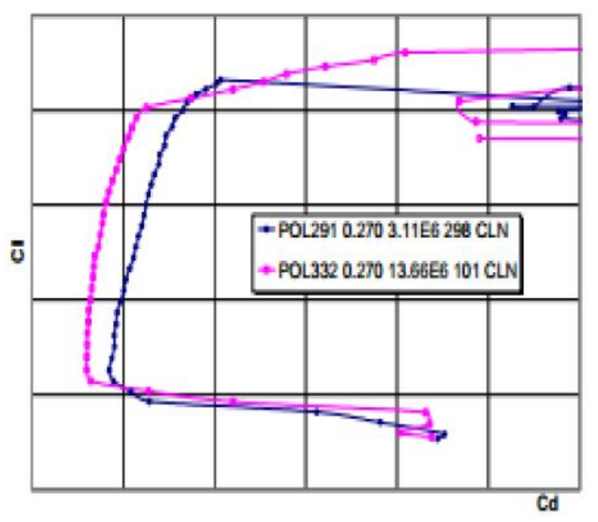


Figure 7: Reynolds Number Effect on Drag for Clean Profile



Reynolds Number Effect of Flow Control Devices

Figures 8 and 9 show the effect of a Gurney flap at two Reynolds numbers. It is clear that the selected Gurney flap suitable for the low Reynolds number is not optimal for the high Reynolds number.

Figure 8: The Effect of Gurney Flap on the Change of Lift Referred to the Clean Profile at Two Reynolds Numbers

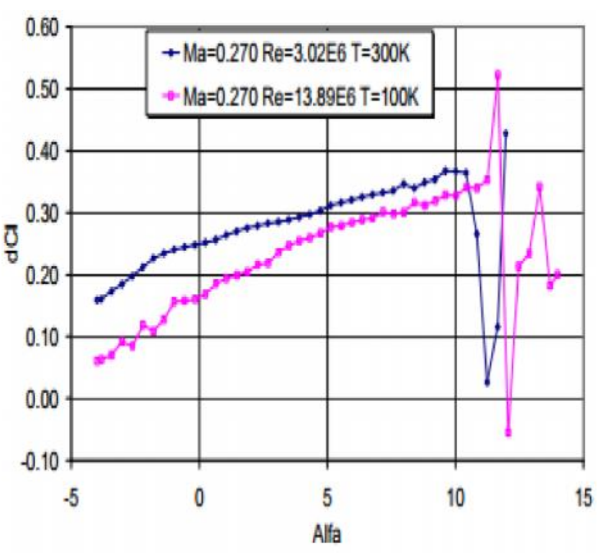
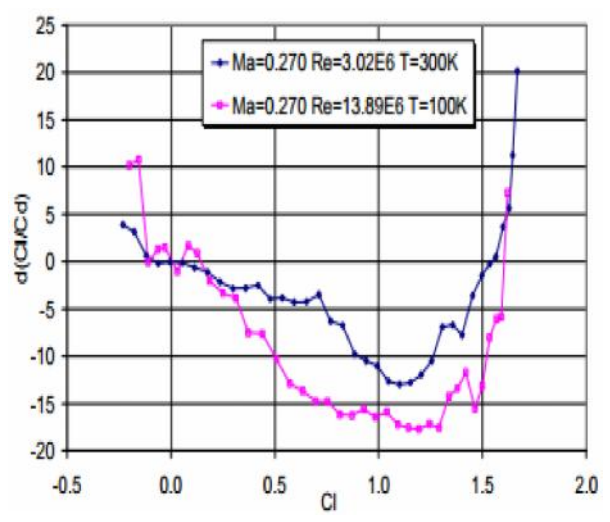


Figure 9: The Effect of Gurney Flap on the Change of Lift Drag Ratio Referred to the Clean Profile at Two Reynolds Numbers

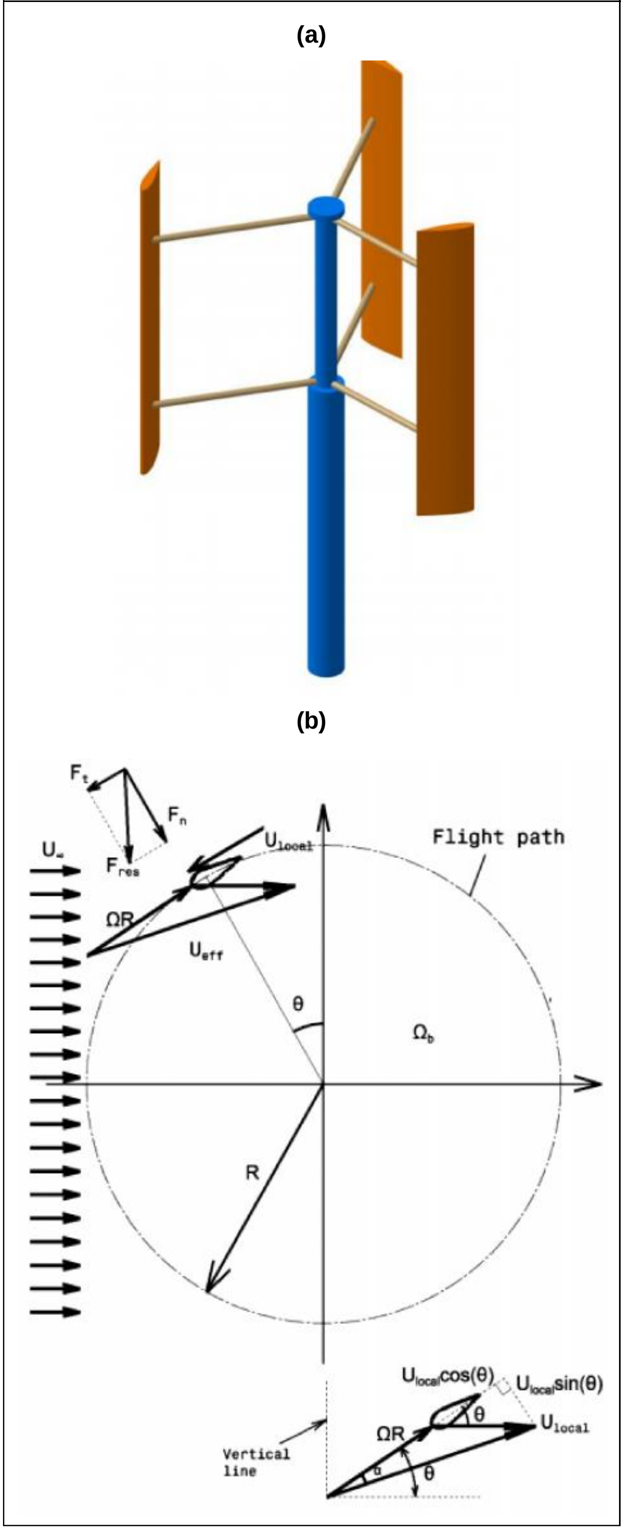


AERODYNAMICS OF A VAWT

The movement of the blades in a VAWT entails a large range of flow regimes from rest to the operating condition. In order to understand the starting behavior, it is useful to consider the flow conditions experienced by the turbine blade when it rotates around its vertical axis.

Figure 10a is a schematic of a straight-bladed-fixed-pitch VAWT which is the simplest, but typical form, of the Darrieus type VAWTs. Despite the simplicity, its aerodynamic analysis is still quite complex. One feature is that the relative velocities perceived by the blade always change as the blade moves at different azimuthal positions. Figure 10b illustrates typical flow velocities around a rotating VAWT blade at a given azimuthal angle ¯, as well as the aerodynamic forces perceived by the blade. The azimuthal angle ¯ is set to be zero when the blade is at the top of the flight path and is increases in a counter-clockwise direction.

Figure 10: Basics of VAWT: a) Sketch of a Fixed-Pitch Straight-Bladed VAWT; b) Typical Flow Velocities in Darrieus Motion



From the vectorial description of velocities, Figure 10b, we can obtain the following expression that establishes the relationship between the angle of attack D the Tip Speed Ratio (TSR) ª and the azimuthal angle ¯ of a blade in Darrieus motion (without velocity induction)

$$\tan\sim_D = U_\infty \sin^{-}/(\Omega R + U_\infty \cos^{-})$$

$$= \sin^{-}/(ª + \cos^{-})$$

or $$\sim = \text{arc}\tan(\sin^{-}/ª + \cos^{-})$$

Another important parameter is the reduced frequency which governs the level of unsteadiness.

The reduced frequency *k*, defined as *k*µ = c/2*Ueff* where µ is the angular frequency of the unsteadiness, *c* is the blade chord and *Ueff* is the velocity of the blade, can be expressed in terms of TSR as:

$$k = (c/d)ª/\sqrt{(ª^2 + 2ª \cos^{-} + 1)}$$

TIP SPEED RATIO OF WIND TURBINE

The Tip Speed Ratio (TSR) is an extremely important factor in wind turbine design. TSR refers to the ratio between the wind speed and the speed of the tips of the wind turbine blades.

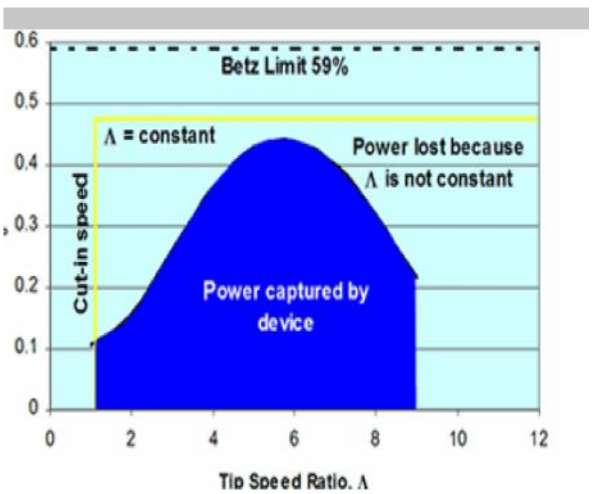
$$TSR(ª) = \frac{Tip\ Speed\ of\ Blade}{Wind\ Speed}$$

The Tip Speed Ratio (often known as the TSR) is of vital importance in the design of wind turbine generators. If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively if the rotor turns too quickly, the blurring blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible.

Optimum Tip Speed Ratio

The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind. A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3. Different types of turbine have completely different optimal TSR values-for example a Darrieus wind turbine is a vertical axis (VAWT) design with aerofoil blades which generate aerodynamic lift and therefore the TSR can be high, but a Savonius wind turbine which is also a VAWT is a drag design and so the TSR will always be less than 1-i.e., it cannot spin faster than the wind hitting it.

Figure 11: Tip Speed Ratio



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