Review on Aerodynamic Performance Evaluation of Straight Blade Vertical Axis Wind Turbine

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Abstract— As the energy crisis is getting severe in the world it will be important to investigate alternative methods of generating power in ways different than, fossil fuels. In fact, one of the biggest sources of energy is all around us all of the time, the wind. Currently, horizontal axis wind turbines (HAWT) dominate the wind energy market due to their large size and high power generation characteristics. However, vertical axis wind turbines (VAWT) are capable of producing a lot of power, and offer many advantages for small-scale and domestic applications. One drawback of DARRIEUS type VAWT is their inability to reliably self-start at low tip speed ratio. The details of different configurations and performance evaluation techniques along with the major findings of researchers on vertical axis wind turbines are reviewed in this paper. The main purpose of the study described here is to investigate effect of different design parameter on performance evaluation of VAWT.

Key words: Darrieus Turbine, Wind Power, CFD, Self-Starting.

NOMENCLATURE

A = cross section area
Cp = performance coefficient
c = chord (m)
D = diameter of the wind turbine (m)
R = radius of the wind turbine (m)
σ = solidity
t = time in seconds
U_∞ = free stream velocity (m/sec)
U_{rot} = rotational Speed of Turbine
α = angle of attack
β = azimuth angle
ω = rotational speed (rad/sec)
ρ = density of air
CFD = computational fluid dynamics
VAWT= vertical axis wind turbine
HAWT=horizontal axis wind turbine
TSR = tip speed ratio

I. INTRODUCTION

Wind power is a vital source of environmental-friendly energy and becomes more important in the recent years. The amount of installed wind power is increasing every year and many nations have made plans to make large investments in wind power in the near future.

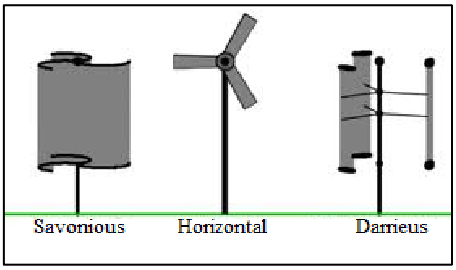

Fig 1: Types of Wind Turbine

There are many different types of wind turbines and they can be divided into two groups of turbines depending on the orientation of their axis of rotation, namely horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) as shown in Fig.1. Vertical axis wind turbines (VAWTs) are the lesser known type of wind turbine.

Merits of vertical axis wind turbines over horizontal axis wind turbines are shown in Table-1.

Parameter	**Vertical axis wind turbine (VAWT)**	**Horizontal axis wind turbine (HAWT)**
Tower Sway	Small	Large
Yaw Mechanism	No	Yes
Self-Starting	No	Yes
Overall Formation	Simple	Complex
Generator Location	On ground	Not on Ground
Height from ground	Small	Large
Blades operation Space	Small	Large
Noise Produced	Less	Relatively high
Wind Direction	Independent	Dependent
Obstruction for Birds	Less	High
Ideal Efficiency	More than 70%	50-60%

Table 1 Merits of VAWT over HAWT [1]

There are two principle designs of VAWTs, the Savonius type and the Darrieus type though there are several configurations of the Darrieus type. Some of these Darrieus configurations are the focus of current research. Straight Blade Darrieus, type VAWT, also called giromill and cyclo-turbine, have been manufactured in recent years with different specifications. There are some parameters which affect the performance of these turbines. Some of the most significant variables are Turbine solidity, Number of blades, Airfoil selection, Blade pitch angle and Turbine aspect ratio (H/D).

The comparative study by Sandra Eriksson et al. [2] has shown that VAWTs are advantageous to HAWTs in several aspects. Furthermore, common misjudgments about VAWTs have been discussed. When comparing the two types of VAWTs considered here, the H-rotor seems more advantageous than the savonious turbine. The strength of the H-rotor concept is the possibility to keep the structure simple. The H-rotor does not require any yaw mechanism, pitch regulation or gearbox and therefore has few movable parts. Another advantage is its expected low need of maintenance. The study of the aerodynamics of a Darrieus turbine is quite fascinating [3].

M. El-Samanoudy et al. [4] has been investigated performance of VAWT with varying the design parameters such as, pitch angle, number of blades, airfoil type, turbine radius and its chord length. Vast numbers of experiments have been performed with changing the above mentioned parameters. The effect of each parameter on the power coefficient and torque coefficient has been studied and explanation of the results was also discussed. It has been found that the pitch angle, turbine radius and chord length have a significant effect on turbine power coefficient. Payam Sabaeifard et al. [5] also did computational and experimental study into the aerodynamics and performance of small scale Darrieus-type straight-bladed VAWT and as a result, it has been found that a 3-bladed turbine with 35% solidity has the best self-starting ability and efficiency among all geometries.

Jon De Coste [6] made model of SB-VAWT using NACA0012 profile evaluate the performance of it. It was found that VAWT performs well at certain TSR. At starting it faces negative torque which is referred as “dead band” in which low or negative torque makes unable to start turbine as low TSR. So, it considers as major drawback of VAWT.

Shrikant D. Had et al. [7] analyze the effectiveness of CFD used to simulate various airflows and directions for a model of VAWT. For accurately predicting the performance of a VAWT various computational models can be used that can numerically predict the wind turbine performance and offers a tremendous benefit over classic experimental technique.

Detailed analysis is done for symmetric NACA airfoils that are commonly referenced in the literature with 12%, 15% and 18% thickness by Haris Hameed Hammad Rahman et al. [8] using CFD simulation. The results are presented for TSR range from 1.0 to 4.0 and for a range of oncoming wind velocities from 6 m/sec to 14 m/sec. The NACA0022 gives the best overall performance. Although the NACA0012 gives a good performance at higher rotational speeds or TSR, it performance at lower rotational speeds is quite low. NACA0015 gives the steady performance. NACA0012 and NACA0015 gives better performance at TSR=4.

N.C. Batista et al. [9] focuses on presenting a new methodology for fast development of new blade profiles, for self-start capable Darrieus wind turbines, which is a complex and time-consuming task. A new methodology is introduced in cooperation with the JavaFoil computational tool, to study these phenomena, as a fast approach for comparing the several blade profile design modifications and enhancements in new airfoil developments .Travis J. Carrigan et al [10] demonstrate a fully automated process for optimizing the airfoil cross-section of VAWT. This work successfully demonstrated a fully automated process for optimizing the airfoil cross-section of a VAWT. Kinloch Kirke Brian [11] studied ways for self-starting of the turbine , performance prediction and different parameters of airfoil which affect the performance.

Ghosh et al. [12] studied some aspects of VAWTs, such as design and performance have been reviewed with regard to Savonius, H-Darrieus and combined Savonius-Darrieus turbines. It was found that the combined Savonius-Darrieus turbine was the best of all the turbines reviewed in terms of power coefficient. Thus, the combined Savonius-Darrieus turbine may be used for small-scale applications by scaling-up the turbine. K.K. Sharma et al. [13] studied performance measurement of a Three-Bladed Combined Darrieus-Savonius Rotor. Result agrees with Darrieus-Savonius rotor can be suitably placed in the built environment where it can harness more power from wind and, at the same time, would self-start in low wind condition prevalent in such environment.

Rosario Lanza fame et al [14] describes the strategy to develop a 2D CFD model of H-Darrieus Wind Turbines. The model was implemented in ANSYS Fluent solver to predict wind turbines performance and optimize its geometry. As the RANS Turbulence modelling plays a strategic role for the prediction of the flow field around wind turbines, different Turbulence Models were tested. The results demonstrate the good capabilities of the Transition SST turbulence model compared to the classical fully turbulent models. The 2D CFD model was calibrated and validated comparing the numerical results with two different type of H-Darrieus experimental data, available in scientific literature. A good agreement between numerical and experimental data was found.

II. DARRIEUS TYPE VERTICAL AXIS WIND TURBINE CONCEPT

A. *Working Principal:*

A Darrieus, or H-Darrieus, VAWT works on the principle of lift to generate torque. As the turbine rotates, the vector summation of the incoming wind velocity with the rotational velocity of the blade creates an angle of attack, resulting in a lift force. When broken down into components, the thrust component contributes to the turbine rotation; whereas the fluctuating radial component can lead to turbine vibration and blade fatigue (see Figure 2).

Both a rotational velocity component and an external wind velocity are required in order to have sustained rotation. The blade preset pitch angle, β, is defined as the angle between the blade chord and the tangent to the swept arc at the mount point, as shown in Figure 2.

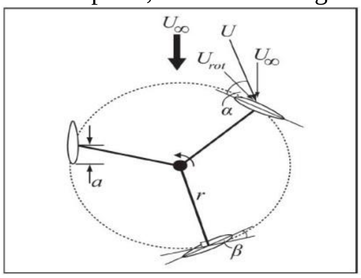

Fig 2: Plan view of turbine showing the preset blade pitch angle (β), angle of attack (α), the incident wind speed due to U_∞ and rotational speed U_{rot}, and mount location offset (a).

B. *Performance Evaluation:*

Wind turbine performance is commonly characterized by the relationship of the coefficient of performance (Cp) to the turbine tip speed ratio as shown in Figure 3. The turbine Cp is defined as:

$$Cp = \frac{P_{Out}}{0.5\rho U_\infty^2 S} \qquad (1)$$

Where U∞ is the nominal wind speed, ρ is the air density, and S is the swept area of the turbine (for an H-Darrieus, S = L × D, where L is the blade length, and D is the turbine diameter).

The tip speed ratio (abbreviated here as TSR) is the ratio of the turbine blade speed to the nominal wind velocity, and is given by:

$$TSR = \frac{\omega R}{U_\infty} \quad (2)$$

Where ω is the angular velocity of the turbine, and R is the equatorial radius.

Other parameters which are used to distinguish between various turbine configurations include the chord radius ratio, c/r, and the turbine solidity which is the ratio of turbine blade area to turbine swept area, and is expressed as:

$$\sigma = \frac{NC}{R} \quad (3)$$

Where N is the number of blades and C is chord of wind blade.

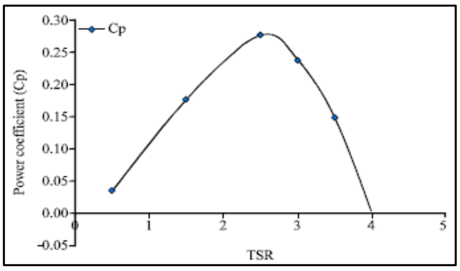

Fig 3: Performance characteristics by Cp Vs TSR graph.

Airfoil profiles used for blades are also importance in the performance of VAWT. The majority of VAWTs utilize NACA airfoil sections because they are easy to manufacture and their characteristics are widely available. The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA".

The NACA four-digit wing sections define the profile in which first digit describing maximum camber as percentage of the chord. Second digit describes the distance of maximum camber from the airfoil leading edge in tens of percents of the chord. Last two digits describing maximum thickness of the airfoil as percent of the chord.

III. Conclusion

From review of above literature we can conclude the following points:

- VAWT having good capability of extracting more power from low wind than HAWT. It can be used for domestic purpose like on office, multi-storey buildings.
- It having simple construction and safe and low cost working than HAWT.
- K-€ SST model is best suited for simulation of VAWT using CFD
- It is having poor self-starting capability at low wind speed. This problem must be solved for effective use of VAWT for domestic Purpose
- SB-VAWT having effect of parameters like Blade aerodynamics, Solidity, Pitch angle, Number of blades and TSR on performance. It is proved that 3 blade VAWT more efficient than 2 or 4 blade. Solidity of 0.2- 0.4 are more efficient.

The objective for my PG dissertation is to study of effect of symmetrical and asymmetrical blade profile on self-starting capability of VAWT by experimentation and CFD simulation.

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