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Review on Numerical and Experimental investigation of Multi blade Vertical Axis Wind Turbine

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Abstract: Now a days small straight blade Darrius vertical axis wind turbine are receive more attention compared to horizontal wind turbines due to their advantage in urban use because they generate less noise, overall formation simple and less cost. First an efficient design methodology built on the design parameters like number of blade(four,five,six), Blade profile ,Tip to speed ratio influencing a straight bladed-VAWT (SB-VAWT) aerodynamic performance and determine the optimal range of above parameters for prototype construction. Wind tunnel performance results are presented for cases of different wind velocity, tip-speed ratio and solidity.

The main purpose numerical study described here is to investigate effect of camber in blade profile of NACA0022 SB-VAWT on its Self- Starting capability using CFD simulation. It is found that asymmetric blade profile NACA 2422 and NACA 4422 with camber instead of symmetric blade profile improves self-starting capability of SB-VAWT. Results indicated wind turbine with blades of asymmetric and thick blade-section was generally more suitable for applying to SB-VAWT. All results of above this study can be used the optimization design parameters of VAWT blades in further.

Comparison of the overall multi blade vertical axis wind turbine performance parameters has been studied through numerical simulations and experimental measurements.

Key words: Darrieus Turbine, NACA 0022, CFD, Self-Starting.

A= cross section area (m2)
Cp = performance coefficient
c = chord (m)
H = height of the rotor, (m)
D = diameter of the wind turbine
(m) R = Radius of the rotor, (m)
σ = solidity
t = time in seconds
U∞ = free stream velocity (m/sec)
Urotor = rotational Speed of Turbine
α = angle of attack
β = azimuth angle
ω = rotational speed (rad/sec)
ρ = density of air (kg·m-3.)
CFD = computational fluid dynamics
VAWT= vertical axis wind turbine
HAWT=horizontal axis wind turbine
TSR = tip speed ratio

I. INTRODUCTION

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. The straight-multi bladed Darrieus type turbine is one of the most common type vertical axis wind turbines (VAWT) used to generate electricity from wind energy. There are a number of substantial advantages [1] over HAWTs, such as:

- The VAWT has no need to constantly yaw into the local wind direction.
- Due to the relatively lower rotational speed, VAWTs are typically less noise than HAWTs.

- The manufacturing cost for a very large VAWT could be lower than that for an equivalent HAWT due to the simpler straight constant section blades compared to the complex three dimensional blade shape in HAWTs.
- The VAWT height from ground small as compare to HAWT.

There are some parameters which affect the performance of vertical axis wind turbines. Some of the most significant variables are Turbine solidity, Number of blades, Airfoil selection, Blade chord, Blade pitch angle, Turbine aspect ratio (H/D), Tip speed ratio and Initial angle of attack.

Dominy et al. [2] in his presentation of vertical axis wind turbines explained the potential advantages of using Darrieus type wind turbines in the small scale and domestic applications where the cost, reliability are very important points in addition to the simplicity of design structure, generator and control system. His concern was about the ability of the Darrieus turbines to be self-started.

Sung-Cheoul Roh et al. [3] in his investigation The results confirm that the blade profile directly affects the performance of the straight-blade Darrieus VAWT.High-digit symmetrical NACA profile provides higher power in the low blade speed range than the low-digit symmetrical NACA profile. When the solidity is increasing over a certain value than power behavior of the straight-Blade Darrieus VAWT is considerably different from that of the egg beater type Darrieus VAWT.

Rosario Lanzafame et al. [4] is work on an unsteady 2D CFD model of H-Darrieus VAWT was developed to evaluate rotor performance, support rotor design and wind tunnel experiments. To take account the unsteady rotational effects, a Sliding Mesh Model was used optimizing the time step of the transient solver. Finally considering that good predictive results of the 2D CFD model.

Normunds Jekabsons and Sabine Upnere et al. [5] state that experiment at small angle of attack, but error increases when the angle exceeds 10 degrees. The two-dimensional numerical simulation method used gives larger wind turbine efficiency. 2D simulations are useful for comparison of different wind turbine configurations.

M. El-Samanoudy et al. [6] has been investigated performance of VAWT with varying the design parameters such as, pitch angle, number of blades, 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, number of blades, turbine radius and chord length have a significant effect on turbine power coefficient.

Robert Howell et al. [7] experiment carried out small model research VAWT turbine has been manufactured and tested over a range of operating conditions. Computational predictions of the performance coefficient of this turbine were carried out considering errors and uncertainties in both the CFD simulations and the wind tunnel measurements. The 2D simulations showed a significantly increased performance compared to the 3D simulations.

Liang Cao et al. [8] has been calculate and analysis with the help of CFD is an important means for understanding the aerodynamic performance of vertical axis wind turbine in design. The higher part of wind turbine’s rotation region has large turbulent kinetic energy and the lower part has little turbulent kinetic energy. The value of turbulent kinetic energy in calculation domain increase with the increase of the wind turbine rotational speed.

Chi-Cong Nguyen et al. [9] Numerical Study of Thickness Effect of the Symmetric NACA 4-Digit Airfoils on Self Starting Capability of a 1kW H-Type Vertical Axis Wind Turbine. Three factors affecting on the self-starting capability of the 1 kW H-type vertical axis wind turbine such as starting azimuth position, wind speed, wing profile. The effect of airfoil thickness on start-up time of the wind turbine is highly recommended. The considered 1 kW H-type vertical axis wind turbine can start up well with NACA 0021 airfoil. The vertical axis wind turbine possesses the high self-starting capability at the starting azimuth position of [90°100°].

Jon De Coste et al. [10] 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.

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. [11] using CFD simulation. The results are presented for TSR range from 1.0 to 3.0 and for a range of oncoming wind velocities from 6 m/sec to 10 m/sec. The NACA0022 gives the best overall performance.

Prasad D. Chougule et al.[12] is work on A CFD simulation of selected single aerofoil and designed double aerofoil is performed on his work. The lift coefficient is directly proportional to the power efficiency and found that it is also found that there is not much change in aerodynamic characteristics of the main aerofoil in the double aerofoil design.

B. Roscher et al. [13] investigation on thin and thick blade from NACA 0015 to NACA 0040. From that it can be said that a rotor design with thick blade sections at the root and thin blade sections at the equator is beneficial from an aerodynamic point of view as well as from a structural one.

Du Gang et al. [14] presented RNG κ-ε turbulence model with sliding mesh is suitable for simulating the model aerodynamic of the vertical axis wind turbine. operating range is increase power coefficient and best solidity increases by 15% then the initial solidity.

Samaraweera K.K.M.N.P et al. [15] presented Development of Darrieus-type vertical axis wind turbine for standalone applications. In this paper a theoretical model for the design and performance simulation of Darrieus-type vertical axis standalone wind turbine for energy applications was developed. Results were used to analyse the effects of blade profile, rotor solidity and aspect ratio on the maximum power and torque coefficients, optimum tip speed ratio and ability to self-start which lead to design of optimum rotor configurations. It is found that when the number of blades of the vertical axis wind turbine is increased, it can be seen an apparent improvement of self -starting.

Joseph P. Tillman [16] work on improvement to vertical axis wind turbine blades for benefit in self-starting. In this study the authors have investigated, improvements in airfoil blade design to aid in the starting of an H-rotor vertical axis wind turbine (VAWT) and how these changes would affect the performance of an H-rotor VAWT. The authors concluded that the asymmetric airfoils can enable H-rotor VAWT to self-start though airfoil blades with a greater cord and thicker cross section work better in the lower wind speeds.

II. DARRIEUS TYPE VERTICAL AXIS WIND TURBINE WORKING PRINCIPAL:

A Darrieus and H-Darrieus VAWT works on the principle of lift to generate torque. As the turbine rotates, the vector outline 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 and the fluctuating radial component can lead to turbine vibration and blade fatigue.

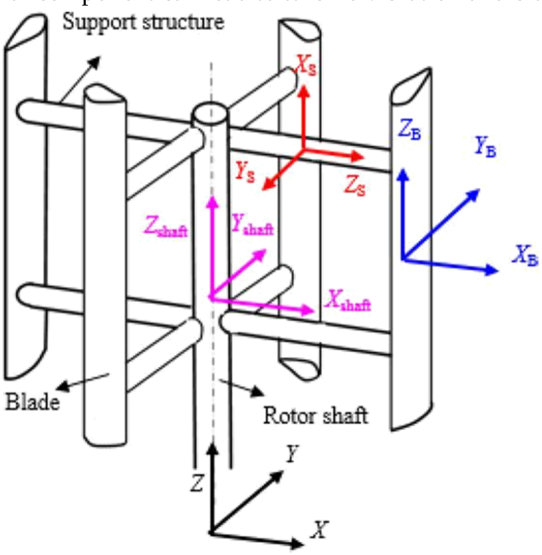

Fig1. Coordinate systems of Vertical Axis Wind Turbine

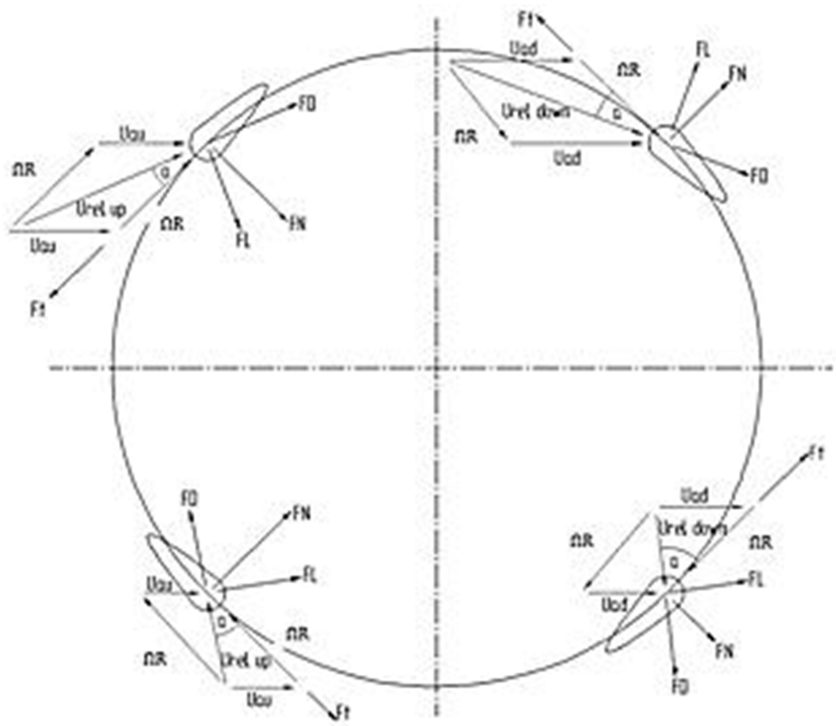

Fig 2.General solution Forces and velocity triangle

The angle of attack α and $\emptyset$ plays a big rule in the forces coefficient direction and magnitude. However, we can illustrate a general solution as shown in Fig.2, where the angle of attack is the only parameter changing the forces coefficient magnitude and direction, as shown above fig.

The power is nothing but the rate of change of angular momentum of wind stream just at Inlet of the test section. Power produced by the rotor was measured from torque and the angular speed using equation. The tip speed ratios were calculated using the measured angular speed values in equation. The torque coefficients can be calculated using the measured dynamic torque data using equation for all the models. Power coefficient can be calculated using the measured torque and angular velocity of the rotor in equation

Rotor Area A= D.H
Angular Velocity $\omega = 2\pi N/60$
Reynolds Number $Re = VD/\nu$
Tip Speed Ratio $\lambda = \omega D/2V$
Power $P = T\omega$
Torque Coefficient $Cq = T/0.5\rho A V^2 R$
Power Coefficient $C_P = P/0.5\rho A V^3$
Drag Coefficient $C_d = F_d/0.5\rho A V^2$
Lift Coefficient $C_l = F/0.5\rho A V^2$

Airfoil profiles used for blades are also importance in the performance of wind turbines. The majority of VAWTs utilize NACA airfoil sections because they are easy to manufacture and their typical are extensive 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 different 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.

CONCLUSION

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

1) VAWT having good capability of generate more power from low wind than HAWT. It can be used for domestic purpose like on office, multi-storey buildings.
2) For CFD analysis 2D and K-€ SST model is best suited for simulation of VAWT.
3) For working model of VAWT suitable material is wood like devdar, balsa.
4) It is found that when the number of blades of the vertical axis wind turbine is increased, it can be seen an apparent improvement of self-starting.
5) VAWT having effect of parameters like Number of blade, Pitch angle, Solidity, blade profile and TSR.
6) For more power generation thick blade is suitable than thin blade.

The objective for my PG dissertation is to optimization of a Small scale vertical axis Wind Turbine Blade and numerical study on effect of thick symmetrical and asymmetrical blade profile capability of VAWT by experimental and CFD simulation.

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