Experimental Investigation on the Performance of Varying Thickness H-Darrieus Rotor

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Abstract. Towards developing wind turbines researchers contributed substantially by doing researches on different blade parameters. However, there is still a good scope of improvement of the VAWTs performance by installing asymmetric blades with rotor modification. The present work enlightens the effect of variable thickness blade considering outward blade pitch angle at low wind speed condition. The thicker portion of varying thickness blade is installed on top of the H-Darrieus rotor. This type of rotor configuration is not efficient for mechanical and electric power generation due achieving less power coefficient in low wind speed condition.

1. Introduction

Wind energy becomes a prominent source of power generation due large wind farm has been installed since last decades. It contains kinetic energy which can be converted to mechanical energy for useful work and also to electrical energy. Wind turbines work as an energy converter; hence efficient design is important. Wind turbine can be classified into two types: Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT). HAWT is more efficient than VAWT, but it requires more wind speed and it has complex in construction. VAWT has certain advantages over HAWT: omnidirectional, easy in installation, less maintenance cost, can work in low wind speed etc. This type of wind turbine is specially used for converting wind energy in urban areas, where direction of wind constantly changes [1]. VAWT can be classified into two types: lift based wind turbine and drag based wind turbine. The lift based wind turbine has more efficient than drag based wind turbine [2], but it has problem of self-starting in low wind speed condition. The Darrieus wind turbine is a lift based wind turbine and can be constructed in different types: straight, helical and eggbeater types. The problem of self-starting has been eliminated by investigating on different parameters by various researchers such as: solidity, blade pitch angle, blade camber, airfoil profile thickness, blade and turbine modifications etc. An extensive study has been carried out on effect of fixed blade pitch angle [3,4], solidity [4–8] on fixed blade pitch angle for different airfoils. Sabaeifard et al. [9] investigated the effect of number of blades (N) and rotor solidity (σ) and concluded that they got best results for N=3 and σ=0.35 with a cambered airfoil DUW200. Ouro et al. [10] studied the performance of symmetric (NACA 0012) and asymmetric (NACA4412) airfoils and concluded that cambered airfoil has an maximum lift to drag ratio than symmetric airfoil. Symmetric airfoils were found batter when turbines were tested in high wind speed conditions [11–13]. This was due to the attachment of flow
with blade in long duration, which is generally obtained in case of symmetric airfoils. But at low wind speed conditions rotor having symmetrical blade cannot be even self-starting. Rezaeiha et al. [3] investigated the effect of blade pitch both inner and outer and recommended that an 6.6% increase in power coefficient ($C_p$) was achieved at outer blade pitch angle 2° at tip speed ratio (TSR) 4. Several modifications in the H-Darrieus rotor have been done such as: combined lift and drag based rotor, multi stage rotor, multi storey rotor for improving self-starting property [14–18]. Chen et al. [14] recommended that the power output is comparatively higher for single stage rotor. Mazarbhuiya et al. [19,20] recommended for NACA 63415 with relative thickness 30%. They also studied the performance of varying thickness having thickness to chord ratio of 37.5% on top and 22.5% on bottom of the rotor. They achieved maximum power coefficient of rotor at low wind speed condition for the varying thickness blade [19]. But, the results for the rotor configuration having t/c of 22.5% on top and 37.5% on bottom has not been shown for low wind speed condition. Hence, in the present work NACA 63415 airfoil having relative thickness 22.5% on top and 37.5% on bottom is considered to investigate the H-Darrieus rotor performance. Flow uniformity across the diameter of the rotor was also studied before investigating the rotor performance.

2. Rotor Fabrication

Due to being one of the potential airfoil NACA 63415 airfoil was selected for fabricating rotor blades [21]. The three bladed H-Darrieus was considered due to better self-starting capability [22] and also have less torque ripple [23] compared to two bladed rotors. The rotor blades have slope 0.3 increasing along blade span length from top. Details of design parameters of the fabricated rotor are given in Table I.

| Details of design parameters | NACA 63415 |
|-----------------------------|------------|
| Airfoil                     | NACA 63415 |
| Chord length (c)            | 0.05 m     |
| Rotor diameter (D)          | 0.5 m      |
| Rotor height (H)            | 0.5 m      |
| Rotor solidity ($\sigma$)    | 0.3        |
| Number of blades (N)        | 3          |

The airfoil having t/c ratio of 22.5% and 37.5% is shown in Fig. 1a. The blades were joined to the shaft by means of strut maintaining rotor diameter 0.5 m angular distance between blades 120°. An outward pitch angle of +5° was incorporated during rotor fabrication as performance was found to be increased for outward blade pitch angle [3]. Sufficient care was taken to maintain the blade shape as original and the procedure is elaborately discussed in reference [19]. The fabricated varying thickness rotor blades are shown in Fig.1b.
FIGURE 1. (a) Top (t/c=22.5%) and bottom (t/c=37.5%) airfoil outline of blade span variable thickness (b) Fabricated rotor blades: RT=t/c=22.5% denotes top and 37.5% denotes the bottom of rotor blades.

3. Experimental Methods
Tests were conducted at the wind tunnel exit placed at NIT Silchar powered by a 20 hp motor. The dimension of the wind tunnel exit was 60 x 60 cm; hence height of rotor blades was kept 50 cm so that wind was completely covered the H-Darrieus rotor. The complete experimental test rig was placed sufficiently away from the contraction cone to get uniform flow from the tunnel. A low wind speed 6.0 m/s was considered and the flow uniformity along the swept area of rotor was investigated which is shown in Fig. 2. The free stream velocity was measured by using digital anemometer having range 0-30 m/s and accuracy of ±2%. The angular velocity of H-Darrieus was measured by using non-contact type tachometer having range 10-99,999 and accuracy of ±0.05%. A rope brake dynamometer arrangement was used for measuring the torque of H-Darrieus rotor.

FIGURE 2. Variation of wind speed across the rotor width

The mechanical torque (T) can be measured using equation 1.

\[ T = (M - S)(r + d)g \]  

Where, M, S, r, d and g denotes weight in Kg, spring balance reading in Kg, radius of the central shaft in m, diameter of string in m and acceleration due to gravity in m/s².

The tip speed ratio is the ratio (\( \lambda \)) between blade speed to wind speed and is expressed in equation 2.

\[ \lambda = \frac{\omega}{2U} \]  

Where, \( \omega \) and U denotes angular velocity of rotor in rad/sec and free stream velocity respectively.

The performance of the rotor can be measured in terms of torque coefficient (C_t) and power coefficient (C_p) expressed in equation 3-4.

\[ C_t = \frac{4T}{\rho U^2 D^2 H} \]  

\[ C_p = C_t \times \lambda \]  

4. Results and Discussions
First of all, the self-starting property of H-Darrieus rotor was investigated at different azimuthal angle shown in Fig 3a. It is clearly depicted that due positive value of static torque (C_q) rotor was self-started in all azimuthal angular (\( \theta \)) positions. The C_q values are also cyclic with a periodicity of 120° due to presence of three blade. The variation of C_q with \( \lambda \) is shown in Fig. 3b. The maximum value of C_q is obtained at tip speed ratio of 1.4. With further increase in \( \lambda \) the value of C_q is decreased. The range of \( \lambda \) is differ with free stream velocity and also with rotor configuration. The variation of C_p with \( \lambda \) is
shown in Fig 3c. The value of $C_p$ increases with increase in $\lambda$ upto some extent and decreases with further increase in $\lambda$. The maximum value of $C_p$ is 0.205 obtained at tip speed ratio of 1.9. The comparison of $C_p$ values with $\lambda$ with one established literature [19] is shown in Fig. 3d. It can be clearly understanding from the plot that rotor having varying thickness with $t/c=37.5\%$ at top and $t/c=22.5\%$ at bottom has superior performance than the present rotor configuration. This is due to the blade thickness effect; rotor can efficiently convert the wind energy to mechanical or electrical energy when upper portion of rotor is comparatively thick than lower portion of rotor. In the present investigation the upper portion of rotor was kept thin compared to lower portion of rotor, due to this reason it cannot convert energy efficiently and hence lower value of $C_p$ is obtained.

![Graphs showing performance of rotors](image)

**FIGURE 3.** (a) $C_q$ vs $\theta$ for understanding self-starting of rotor, (b) $C_t$ vs $\lambda$ at wind speed 6.0 m/s, (c) $C_p$ vs $\lambda$ at wind speed 6.0 m/s, (d) Comparison of performance with existing literature.

5. Conclusions
In the present investigation NACA 63415 airfoil was considered for fabricating varying thickness blade having $t/c=22.5\%$ on top of rotor and $t/c=37.5\%$ on bottom of rotor blade. A pitch angle of $+5^\circ$ was considered due to batter better aerodynamic performance. The following observations is made after this investigation.

- The H-Darrieus rotor was self-started at all azimuthal angular positions since all the $C_q$ values were positive.
The $C_t$ value is maximum at tip speed ratio 1.4 and is continuously decreased with further increase in $\lambda$.

The $C_p$ value was increasing with increase in $\lambda$ up to some extent and decreased with further increase in $\lambda$.

The present $C_p$ value is 0.205 at tip speed ratio of 1.9 which is less compared to $t/c=37.5\%$ on top and $t/c=22.5\%$ on bottom of H-Darrieus rotor.

This rotor configuration is not recommended for standalone application for generation of mechanical or electrical energy due to less value of $C_p$.

References

[1] Kenjeres S, de Wildt S, Busking T. Capturing transient effects in turbulent flows over complex urban areas with passive pollutants. Int J Heat Fluid Flow 2014;51:120–37. doi:10.1016/j.ijheatfluidflow.2014.10.024.

[2] Mohamed MH. Impacts of solidity and hybrid system in small wind turbines performance. Energy 2013;57:495–504. doi:10.1016/j.energy.2013.06.004.

[3] Rezaieha A, Kalkman I, Blocken B. Effect of pitch angle on power performance and aerodynamics of a vertical axis wind turbine. Appl Energy 2017;197:132–50. doi:10.1016/j.apenergy.2017.03.128.

[4] Fiedler AJ, Tullis S. Blade Offset and Pitch Effects on a High Solidity Vertical Axis Wind Turbine. Wind Eng 2009;33:237–46. doi:10.1260/030952409789140955.

[5] Lee Y-T, Lim H-C. Numerical study of the aerodynamic performance of a 500 W Darrieus-type vertical-axis wind turbine. Renew Energy 2015;83:407–15. doi:10.1016/j.renene.2015.04.043.

[6] Parra-Santos MT, Uzarraga CN, Gallegos A, Castro F. Influence of Solidity on Vertical Axis Wind Turbines. Int J Appl Math Electron Comput 2015;3:215. doi:10.18100/ijamec.42848.

[7] Saghari A, Zamani M, Ghasemi A. Effect of solidity on the performance of variable-pitch vertical axis wind turbine. Energy 2018;1–4. doi:10.1016/j.energy.2018.07.160.

[8] Subramanian A, Yogesh SA, Sivanandan H, Giri A, Vasudevan M, Mugundhan V, et al. Effect of airfoil and solidity on performance of small scale vertical axis wind turbine using three dimensional CFD model. Energy 2017;133:179–90. doi:10.1016/j.energy.2017.05.118.

[9] Sabaeifard P, Razzaghi H, Forouzandeh A. Determination of Vertical Axis Wind Turbines Optimal Configuration through CFD Simulations. 2012 Int Conf Futur Environ Energy 2012;28:109–13.

[10] Ouro P, Stoesser T, Ramirez L. Effect of blade cambering on dynamic stall in view of designing vertical axis turbines. J Fluids Eng 2018;140:1–12. doi:10.1115/1.4039235.

[11] Hashem I, Mohamed MH. Aerodynamic performance enhancements of H-rotor Darrieus wind turbine. Energy 2018;142:531–45. doi:10.1016/j.energy.2017.10.036.

[12] Kanyako F, Janajreh I. ICREGA’14 - Renewable Energy: Generation and Applications 2014. doi:10.1007/978-3-319-05708-8.

[13] Mohamed MH. Performance investigation of H-rotor Darrieus turbine with new airfoil shapes. Energy 2012;47:522–30. doi:10.1016/j.energy.2012.08.044.

[14] Chen J, Liu P, Xu H, Chen L, Yang M, Yang L. A detailed investigation of a novel vertical axis Darrieus wind rotor with two sets of blades. J Renew Sustain Energy 2017;9. doi:10.1063/1.4977004.

[15] Bhuyan S, Biswas A. Investigations on self-starting and performance characteristics of simple H and hybrid H-Savonius vertical axis wind rotors. Energy Convers Manag 2014;87:859–67. doi:10.1016/j.enconman.2014.07.056.

[16] Debnath BK, Biswas A, Gupta R. Computational fluid dynamics analysis of a combined three-bucket
Savonius and three-bladed Darrieus rotor at various overlap conditions. J Renew Sustain Energy 2009;1:033110. doi:10.1063/1.3152431.

[17] Frunzulica F, Cismilianu A, Boros A, Dumitrache A, Suatean B. A new vertical axis wind turbine design for urban areas. AIP Conf Proc 2016;1738. doi:10.1063/1.4952209.

[18] Malge A, Pawar P. Wind tunnel and numerical performance analysis of multi-storey vertical axis wind turbines. J Renew Sustain Energy 2015;7. doi:10.1063/1.4934721.

[19] Mazarbhuiya HMSM, Biswas A, Sharma KK. Performance investigations of modified asymmetric blade H-Darrieus VAWT rotors. J Renew Sustain Energy 2018;033302. doi:10.1063/1.5026857.

[20] Mazarbhuiya HMSM, Biswas A, Sharma KK. Performance Prediction of Asymmetrical Bladed H-Darrieus VAWT Rotors in Low Wind Speed Condition using CFD 2018;020040. doi:10.1063/1.5032002.

[21] Mohamed MH, Ali AM, Hafiz AA. CFD analysis for H-rotor Darrieus turbine as a low speed wind energy converter. Eng Sci Technol an Int J 2015;18:1–13. doi:10.1016/j.jestch.2014.08.002.

[22] Liang Y Bin, Zhang LX, Li EX, Liu XH, Yang Y. Design considerations of rotor configuration for straight-bladed vertical axis wind turbines. Adv Mech Eng 2014;2014. doi:10.1155/2014/534906.

[23] Beri H, Yao Y. Numerical simulation of unsteady flow to show self-starting of vertical axis wind turbine using fluent. J Appl Sci 2011;11:962–70. doi:10.3923/jas.2011.962.970.