CFD Analysis of Airfoils for a VAWT for Low Wind Profile Areas: A Review

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Abstract

The human demands are increasing day by day and which have to be fulfilled by sufficient supply of resources. One of the demand is of energy, the energy requirement is being fulfilled in many way such as thermal power plants. But, we need an efficient way of generating power which does not affect the environment and doesn’t uses fossil fuels. Wind turbines are one of the way to fulfil the demand. Vertical axis wind turbines (VAWTs) are standing still, to face the challenges in low wind profile areas. In this study, airfoil from different series were compared to optimise the performance of a VAWT. This study is done to compare the actual coefficient of lift and drag with the experimental values obtained using CFD. This study also states that CFD analysis is a better way than experiments as they are costly and take a lot of time and labour cost to obtain the values. The CFD analysis was done on 2D section of airfoil to obtain the desired result.

Keywords: VAWT, airfoil design, CFD, Numerical analysis

1. Introduction

This specific model intensifies the wind velocity in its outlet before it reaches the turbine. It increases the maximum power coefficient to an appreciable value of 0.397 at 5m/s wind speed and this facilitates efficient design in the low wind profile area. [1] The difference between the CFD technique and experimental technique conducted on wind tunnel by obtaining coefficient of drag and coefficient of lift. Both the experiments gave approximately same results. The experimental section being costlier and thus declaring that CFD technique is indeed a mature tool for such test performances at any angle of attack.[2] The Darrieus vertical axis wind turbine (VAWT) configurations and also including all the drawbacks of each variation hindering the development into large scale rotor. They mentioned about the curved blades and straight blades configurations, and why some varieties have been stopped and how some have evolved. [3] CFD technique is as good as testing a product experimentally. The experimental test using wind tunnel is costlier than the CFD technique. This paper showed how approximately same values they both provide and thus proving that CFD is a good way to test airfoils and its greatly reliable. [4] The results of test done upon six commonly used airfoils: the M-6, the CYH, the N-22, the C-72, the Boeing 106, and the Gottingen 398. The lifts, drags, and pitching moments of the airfoils were measured through a large range of positive and negative angles of attack. For the N-22, the C-72, the Boeing 106 and the Gottingen 398 airfoils, the negative maximum lift coefficients were found to be approximately half the positive. For the M-6 and the CYH, which have less effective camber, the negative values were, respectively, 0.8 and 0.6 of the positive values. [5] The arms increase the power loss of VAWTs; however, the distribution between the pressure and friction influences and their degrees of influence have not yet been investigated in detail in past research. They applied computational fluid dynamics targeting a small sized straight-bladed VAWT to elucidate the effects of arms on turbine performance. In the analysis they used three kinds of arms with different cross sections. [6]

2. Literature Review

2.1 Vertical Axis Wind Turbine

The performance of a VAWT is influenced by the amplitude and the rate of increase of the angle of attack. Reducing the angle of attack improves the torque coefficient, especially in the upwind area and some areas downstream where a positive torque is generated on a VAWT with variable- pitch blades. [7] SB-VAWTs are potentially more efficient and more economical, but those with fixed pitch straight-blades have been regarded as unsuitable for stand-alone use due to their lack of starting torque production. According to experimental investigation, it has been found that NACA 4415(asymmetric airfoil) can produce significantly higher starting torque than a NACA 0021(symmetric airfoil) at two different solidities.[8] Influences of some parameters on the performance of a small VAWT. A blade profile with a larger thickness yields a higher power coefficient than the one with a smaller thickness in a range of TSR < 3 speed zone. For a TSR > 5 speed zone, the converse holds. There is a clear influence of the pitch angle on the self-starting behaviour of the rotor, i.e., an optimal pitch angle can significantly reduce the acceleration period. The Reynolds number, the thickness and the pitch angle of the NACA (and others) blade profile(s) are the main parameters that influence the second acceleration step.[9] CFD analysis of different blades in VAWT. The Savonius type VAWT shows better starting torque at low wind speed. The increasing wind speed and tip speed ratio are better for the Darrieus type of VAWT. For the Domestic purpose, Savonius type VAWT shows the better result as the average wind speed will produce regular power supply. For regions with higher wind velocity, Darrieus type VAWT proves to be more efficient.[10] Efficiency of a VAWT with airfoil pitch control. Torque with respect to the rotation centre of a VAWT depends on wind angle of attack and support arm position. Wind speed has insignificant effects on both torque magnitude and distribution pattern. For the NACA 0012 airfoil investigated in this study, the torque always peaks out at 90° angle of attack at any given support arm position. A control mechanism to maintain the airfoil at a constant 90° angle of attack is the optimal pattern for maximum efficiency and energy production. [11] Design and Fabrication of VAWT with Magnetic Repulsion. In the current attempt solidity, number of blade, chord length, etc. are the basic consideration for design and development. All efforts were made to develop the model to generate the output even at low wind speed. Magnets are used to increase the starting torque by using repulsive force. And in the attempt, self-starting speed is 1.08m/s which is much lower. Also turbine is in motion once it starts even after speed is less than 1.08m/s. This is due to repulsive force of the magnets used. [12] Wind tunnel experiments were performed to evaluate the power coefficients of three VAWTs - (a) conventional VAWT (two-bladed troposkien shape), (b) novel 50% shifted troposkien shape-vertical axis wind turbine (50% STS-VAWT), and (c) novel 100% STS-VAWT. The 50% STS-VAWT model showed an overall better aerodynamic performance when compared against the other two configurations, due to a combination of (a) power generation increased due to blade-wake interaction (BWI) reductions and (b) power generation capacity related to the blade length of each turbine. [13] From a geometrical point of view, as aspect ratio falls, the Reynolds number rises which improves wind turbine performance [14] This research has made an attempt to utilize at low velocity wind below 4m/s for useful power generation using magnetic levitation for vertical axis wind turbine (VAWT) termed as Maglev turbine. The efficiency of turbine is increased by replacing the conventional bearings by magnets in repulsion; the magnetic levitation helps the turbine to spin at much faster rate as it eliminates the stresses on the shaft of turbine. [15] Vertical axis wind energy conversion systems are practical and potentially contribute to the production of clean renewable electricity from the wind, helpful in rural areas where the electricity supply is scarce. [16] The airfoil in the upwind condition is responsible for the lift generation and consequent torque production for the turbine. Thus, a fixed pitch, helical VAWT has been designed, modelled, fabricated, wind tunnel-tested, and analysed using CFD. The number of vortices gets reduced as the RPM was increased; however, the intensity of the low pressure region at the centre showed an increase. [17] The actuator cylinder flow model has been defined as the ideal VAWT rotor. A variable pitch of the blades or continuous control of lift by flaps could improve the loading. It was also found that an increase in airfoil drag of 0.001 leads to a 1% decrease in power coefficient. [18] The flow characteristics and wind energy utilizations of H-type VAWT blade and its trailing edge modification while having a certain camber to facilitate a greater understanding of the effects of airfoil trailing edge thickness and relative camber has been put to investigation. With the NACA series airfoil NACA0021, whose tailing-edge thickness is 0.442%c (c cord length) and the simulation accuracy of the CFD approach was validated through comparing the calculated result. [19] To demonstrate the viability of the applying adjoin methods for the optimization technique for aerodynamics of a VAWT. These methods are very powerful optimization techniques which have been implemented effectively in many other fields. The outcomes of the novel blade geometries shows the improvement in the VAWT average power coefficient when compared to the original NACA0018 blade. [20] There have been many studies on the HAWT and the VAWT icing is been seldomly reported in the literature. The ice accretion shape of the static VAWT blade must be tested under various angles of attacks. Ice accretion shapes are obtained at the range of -25 to 25 degree angle of attack. Finally, after the testing it was found that iced CAWT loses up to 60% of power performance due to time ice conditions. The VAWT will be unable to produce power in the glaze ice. [21] The VAWT are of many types and can be modified and designed for better efficiency and to do that wind flow modifiers (WFM) is one of the solution. This work concentrates on the design and analysis of different wind flow modifiers to achieve better efficiency of the VAWT. To monitor the performance of the rotor blades numerical analysis is performed with a realizable K-epsilon model. [22]

Coefficient of lift and drag

The coefficient of lift and drag can be obtained numerically as well as experimentally and in this abstract the work has been done on both and has been compared. Analysis of airfoil over two-dimensional subsonic flow at various angle of attack and at certain Reynolds number is obtained. [23] The accuracy of the CFD simulation of the VAWT is associated with the computational parameters, such as azimuthal increment, domain size and number of turbine revolutions before reaching a statistically steady state convergence. [24] As a main component in the design method, airfoil profile are expressed in a trigonometric series form using conformal transformations and series of polynomial equations. A new method is presented in this paper for designing turbine airfoils. To validate and show the generality of the trigonometric expression, the profiles of the NACA 64418 and S809 airfoils are expressed by the present expression. [25] Numerical simulation and wind turbine experiment was carried out using a small SB-VAWT symmetric airfoil modelS1046 and NACA0018 and an asymmetric airfoil S809. The work was done to investigate the effect of aerodynamic characteristics of S series airfoils on the straight bladed vertical axis wind turbine. [26] There are many wind turbine developments in the recent time for the urban and suburban areas application. But, the efficiency of the wind turbine is the major issue for everyone. This project include the CFD analysis of the power augmented shroud which can be helpful in the improvement of the performance of the VAWT. The shroud was experimented using the NACA0015 airfoil. [27]

3. Discussion

The researchers are going on with high speed in order to get better resources and the cost of practical experiments kept increasing due to the complexity of experiment. To overcome the cost, labour and time CFD has been one of the best way to achieve the desired result with high precision. In most of the wind turbines blade design is one of the crucial factor in increasing the efficiency of the wind turbine. Keeping in mind the current efficiency for a VAWT is low for a Savonius vertical axis wind turbine has an average efficiency of 10 to 17 %, while the Darrieus vertical axis wind turbine reaches 30 to 40 %. For low wind profile areas and for city areas the HAWT (Horizontal Axis Wind Turbine) is not the best choice as it requires large area and high maintenance cost. For this comes forward the VAWT (Vertical Axis Wind Turbine). VAWT can be installed even on small roofs and can be helpful in low wind profile areas.

4. Conclusion

An attempt was made to identify which NACA series blades will be better for the VAWT and compare them with the originally used NACA 0012. CFD was used to analyse the lift and drag coefficient of the blade for a 3d profile of an airfoil. CFD decreased the experiment time and nearly no cost was involved to do the numerical analysis of the airfoil. A better camber airfoil has better lift and stall characteristics which are helpful for a VAWT as it is a lift type wind turbine.

References

[1] Anthony, Mohanasundaram; Prasad, Valsalal; Raju, Kannadasan; Alsharif, Mohammed H.; Geem, Zong W.; Hong, Junhee. 2020. "Design of Rotor Blades for Vertical Axis Wind Turbine with Wind Flow Modifier for Low Wind Profile Areas" *Sustainability* 12, no. 19: 8050.

[2] Rajat Veer, Kiran Shinde, Vipul Gaikwad , Pritam Sonawane, Yogesh Sonawane, 2017, Study and Analyse Airfoil Section using CFD, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 06, Issue 09 (September 2017).

[3] Willy Tjiu, Tjukup Marnoto, Sohif Mat, Mohd Hafidz Ruslan, Kamaruzzaman Sopian,Darrieus vertical axis wind turbine for power generation I: Assessment of Darrieus VAWT configurations, Renewable Energy, Volume 75, 2015, Pages 50-67, ISSN 0960-1481.

[4] Karna S. Patel, Saumil B. Patel, Utsav B. Patel, Prof. Ankit P. Ahuja, "CFD Analysis of an Aerofoil", International Journal of Engineering Research, March 2014, ISSN:2319-6890, Volume No.3, Issue No.3, PP 154-158.

[5] Anderson R F, the Aerodynamic Characteristics of Six Commonly Used Airfoils over a Large Range of Angle of Attack, National Advisory Committee for Aeronautics, 1931.

[6] Hara, Yutaka & Horita, Naoki & Yoshida, Shigeo & AKIMOTO, Hiromichi & Sumi, Takahiro. (2019). Numerical Analysis of Effects of Arms with Different Cross-Sections on Straight-Bladed Vertical Axis Wind Turbine. Energies. 12. 2106. 10.3390/en12112106.

[7] Rachmat FIRDAUS, Takahiro KIWATA, Takaaki KONO, Koji NAGAO, Numerical and experimental studies of a small vertical-axis wind turbine with variable-pitch straight blades, Journal of Fluid Science and Technology, 2015, Volume 10, Issue 1, Pages JFST0001.

[8] Islam, Mazharul, "Analysis of fixed-pitch straight-bladed VAWT with asymmetric airfoils" (2008). Electronic Theses and Dissertations. 7977.

[9] Alexandru Dumitrache, Florin Frunzulica, Horia Dumitrescu, Bogdan Suatean, Influences of some parameters on the performance of a small vertical axis wind turbine, Renew. Energy Environ. Sustain. 1, 16 (2016).

[10] Dr T.Mothilal, P.Harish Krishna, G.Jagadeesh Babu, Ashwin Suresh, K.Baskar, S.Kaliappan, M.D.Rajkamal,"CFD Analysis of Different Blades in Vertical Axis Wind Turbine," International Journal of Pune and Applied Mathematics, Volume 119 No. 12 2018, 13545-13551.

[11] J.Ma, C.Koutsougeras, H.Luo, "Efficiency of a Vertical Axis Wind Turbine (VAWT) with Airfoil Pitch Control," COMSOL Conference 2017.

[12] Shubham Nandurkar, Tirthraj Lonare, Vaishnavi Fulzele, Pranay Bagde,"Design and Fabrication of Vertical Axis Wind Turbine with Magnetic Repulsion", International Journal of Engineering Research and Technology (IJERT), Vol. 6 Issue 05, May-2017.

[13] Hilewit, Doma & Matida, Edgar & Fereidooni, Amin & Ella, Hamza & Nitzsche, Fred. (2019). Power coefficient measurements of a novel vertical axis wind turbine. Energy Science & Engineering. 7. 10.1002/ese3.412.

[14] Brusca, S. & Lanzafame, R. & Messina, Michele. (2014). Design of a vertical-axis wind turbine: how the aspect ratio affects the turbine's performance. International Journal of Energy and Environmental Engineering. 5. 1-8. 10.1007/s40095-014-0129-x.

[15] Deshmukh, Samir & Charthal, Sagar. (2017). Design and Development of Vertical Axis Wind Turbine. IRA-International Journal of Technology & Engineering (ISSN 2455-4480). 7. 286. 10.21013/jte.ICSESD201728.

[16] Gulve, Piyush & Barve, Dr. Shivprakash. (2014). DESIGN AND CONSTRUCTION OF VERTICAL AXIS WIND TURBINE. 5. 148-155.

[17] Rajesh Senthil Kumar, T. & Ananth, Raju & Nair, Chithra & Das, Vaisakh & Ravindran, Vishwanath. (2011). Design,Testing and Analysis of a Vertical Axis Wind Turbine.

[18] Madsen, Helge & Paulsen, Uwe & Vitae, L. (2014). Analysis of VAWT aerodynamics and design using the Actuator Cylinder flow model. Journal of Physics: Conference Series. 555. 012065. 10.1088/1742-6596/555/1/012065.

[19] Zhang, Xu & Li, Zhaoxuan & Yu, Xiang & Li, Wei. (2019). Aerodynamic Performance of Trailing-Edge Modification of H-Type VAWT Blade Considering Camber Effect. International Journal of Aeronautical and Space Sciences. 21. 10.1007/s42405-019-00241-x.

[20] Day, Harry & Ingham, Derek & Ma, Linsha & Pourkashanian, M.. (2020). Adjoint based optimisation for efficient VAWT blade aerodynamics using CFD. Journal of Wind Engineering and Industrial Aerodynamics. 208. 104431. 10.1016/j.jweia.2020.104431.

[21] Manatbayev, Rustem & Baizhuma, Zhandos & Bolegenova, Saltanat & Georgiev, Aleksandar. (2021). Numerical simulations on static Vertical Axis Wind Turbine blade icing. Renewable Energy. 170. 10.1016/j.renene.2021.02.023.

[22]Design of Rotor Blades for Vertical Axis Wind Turbine with Wind Flow Modifier for Low Wind Profile Areas. Mohanasundaram Anthony 1 , Valsalal Prasad 2, Kannadasan Raju 3 ,Mohammed H. Alsharif 4,* , Zong Woo Geem 5 and Junhee Hong 5,*

[23] Study and Analyse Airfoil Section using CFD Rajat Veer*, Kiran Shinde*, Vipul Gaikwad*, Pritam Sonawane*,

[24] Rezaeiha A, Montazeri H, Blocken B. Towards accurate CFDsimulations of vertical axis wind turbines at different tip speedratios and solidities: guidelines for azimuthal increment, domainsize and convergence. Energy Convers Manage. 2018;156:301-316.

[25] An Integrated Method for Designing Airfoils Shapes Wang Xudong,1,2 Wang Licun,1,2 and Xia Hongjun1.

[26] Neumarical analysis of VAWT wind turbine. Joukowski vs naca rotor blades.Jabir Ubaid Parakkala, Khadije El Kadia, Ameen El-Sinawia, Sherine Elagroudyb, IsamJanajreha,

[27] The design and flow simulation of a power-augmented shroud for urban wind turbine system. K.H. Wong a, W.T. Chong a, *, H. T. Yap a, A. Fazlizan a, W.Z.W. Omar b, c, S.C. Poh a, F.B. Hsiao d.