Computational Analysis of Savonius Wind Turbine Blades

Rupesh Baroniya
Under Graduate Student
Department of Mechanical Engineering
ITM Group of Institutions, Gwalior, India

Sulabh Shrivastava
Under Graduate Student
Department of Mechanical Engineering
ITM Group of Institutions, Gwalior, India

Rahul Rathore
Under Graduate Student
Department of Mechanical Engineering
ITM Group of Institutions, Gwalior, India

Vikram Singh Bhadoriya
Under Graduate Student
Department of Mechanical Engineering
ITM Group of Institutions, Gwalior, India

Abstract

The Savonius wind turbine is one of the most widely used vertical axis wind turbines. To achieve maximum efficiency, a twist angle is provided in the turbine blades. This paper gives a detailed explanation of the effect of the twist angle provided to the savonius wind turbine blade to its efficiency. Three-dimensional geometries of the savonius wind turbine with two blades created in SOLIDWORKS 2015 and the flow behavior of air analyzed using ANSYS Fluent 14.0 fluid simulation software. Air at an inlet velocity of 5 m/s, 10 m/s, 15 m/s & 20 m/s passed through the savonius turbine with blades twisted at 0°, 45°, 90° & 180° angles. The maximum theoretical efficiency of the turbine is calculated and compared at different twist angles. The results show that the maximum efficiency of the savonius wind turbine is achievable at a 45° twist angle.
Keywords: Savonius Wind Turbine, Turbine Efficiency, Blade Design, Computational Analysis

I. INTRODUCTION

Vertical axis wind turbines are always known for their low overall efficiency as compared to a horizontal axis wind turbine. Savonius wind turbine, one of the most widely used vertical axis wind turbine also has a similar problem with overall achievable efficiency is somewhere less than 0.30. Even though the savonius wind turbine has such a low efficiency it is mostly used for low development cost and reliability. To improve the achievable efficiency of the savonius wind turbine a twist angle is provided to its blades. This twist angle affects its efficiency and the total power output. The total achievable efficiency and power output of the turbine is depending on the total generated torque and the total number of rotations per minute. The twist angle of the savonius wind turbine blades determines it's contact characteristics with the wind, which ultimately affects its rotational speed and torque generation. The best-suited twist angle of the blades can be determined with the experimental method which gives results based on global parameters, but performing an experimental method is very costly and it requires a different set of blades for the study of different twist angle. This approach is also very time-consuming. The computational fluid dynamics provides an alternative solution to determine the best-suited twist angle for the savonius wind turbine. Which is cost-effective and faster than experimental testing.

II. COMPUTATIONAL METHODOLOGY

Four 3-Dimensional CAD models of the savonius wind turbine with two blades created with the help of SOLIDWORKS 2015. The CAD models of savonius wind turbine blades are twisted at 0°, 45°, 90° & 180°. The various dimensions and parameters of the turbine are given in table 1. The CAD model of the turbine imported in ANSYS fluent 2014 fluid simulation software. The developed CAD model messed with a hexahedral element with a very fine sizing for better accuracy. The various operating and boundary conditions defined. K – epsilon viscous model is used for simulation considering the turbulent flow characteristic of airflow. The first simulation on the turbine with a blade twisted at a 0° angle carried out. Velocity and pressure profile of the blade plotted. The thrust force on the blade is found out. The simulation is repeated with the same CAD model at an inlet velocity of 5 *m/s*, 10 *m/s*, 15 *m/s* and 20 *m/s* and thrust force at a different velocity is found out. The thrust force is used to find out the theoretical maximum possible efficiency of the wind turbine. The simulation is repeated with other models with twist angles at 45°, 90° & 180°. The graphs between the theoretical efficiency and Inlet wind velocity is plotted and compared.

Table – 1

Type of Test Blade	*Savonius*
Blade Height	*1000 mm*
Blade Diameter	*300 mm*
Blade thickness	*10 mm*

Number of Blades	*2*
Twist Angles	*0°, 45°, 90° & 180°*
Type of Model	*K – epsilon*
Mess type	*Hexahedral*
Working fluid	*Air*
Inlet Velocity	*5 m/s, 10 m/s, 15 m/s & 20 m/s*

III. TURBINE EFFICIENCY CALCULATION

The maximum theoretical efficiency of the turbine η is calculated by using the following formula.

$$\eta = \frac{P_t}{P_a} \tag{1}$$

Where, P_t is the power on the rotor and P_a is wind power
The power of the wind can be calculated by the given equation,

$$P_a = \frac{1}{2}\rho A V^3$$

Where ρ is the density of the air $(1.225\ kg/m^3)$, V is the inlet velocity of the wind in m/s and A is the swept area in m^2
The power of the rotor can be calculated by the given equation,

$$P_t = \frac{2\pi NT}{60}$$

Where N is the generated rotation per minutes (RPM) of the turbine and T is the generated torque.
Tip speed ratio λ is a very important factor while calculation of wind turbine power with two or more blades. It provides the effect of the number of blades in a wind turbine. It is the ratio of the speed of the blade tip v to the wind velocity V.

$$\lambda = \frac{v}{V} = \frac{\omega r}{V} = \frac{2\pi Nr}{60V}$$

Where, r is the blade radius, which is half of the turbine diameter D. Tip speed ratio λ for two blade vertical axis wind turbine can be calculated as [6].
The generated torque T on the rotor is given by,

$$T = F_T\,\frac{D}{2}$$

Where D is the diameter in m and F_T is the generated thrust force on the blades. Thrust force on the blade F_T is calculated with the help of ANSYS fluent 14.0 fluid simulation software.

IV. RESULTS

The simulations are carried out on all four turbines with blades twisted at 0°, 45°, 90° & 180°. As these angles are mostly used with a savonius turbine. The simulations are carried out at inlet velocity of 5 *m/s*, 10 *m/s*, 15 *m/s* & 20 *m/s*. As this is an optimal range of wind velocity for a vertical axis wind turbine. The pressure profile for all turbine blades is plotted. The contour of total pressure distribution for all the turbine blades working at an inlet velocity of 15 m/s is shown in fig. 1. After leaving the turbine blades, air creates a large low-pressure area. This area is different for different twist angle. The zero twist angle creates a much larger low-pressure area which means the blade with zero-twist angles has a larger contact area between the air and the blades but it doesn’t mean that the larger area creates better trust force as shown in fig 1. The turbine blade twisted at 45° creates the largest trust force and has lesser contact area as compared to a zero-twist angle blade. Similarly, the turbine blade twisted at 90° creates large trust force and the turbine twisted at 180° creates a large contact area but a comparatively less thrust force.

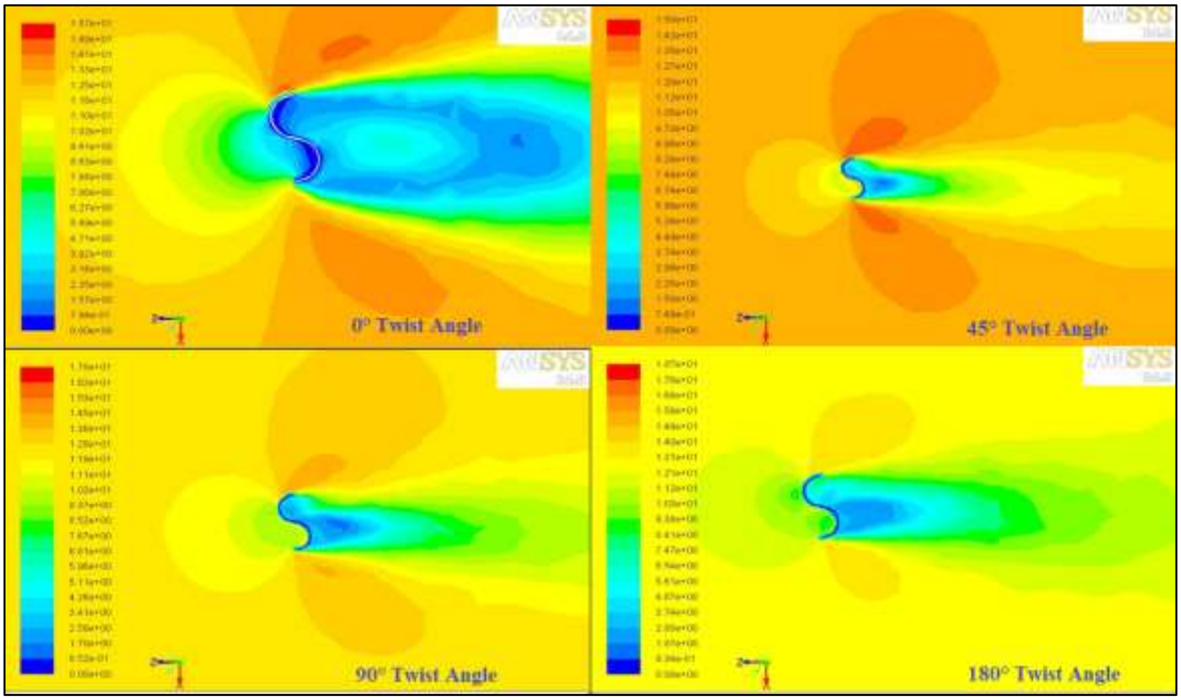

Fig. 1:

The total pressure and the maximum contact area between the wind and the turbine blades are used to find the trust force generated on the turbine blades. The thrust force further used to calculate the power generated by the turbine. The power generated by the turbine and wind power is used to calculate the maximum theoretical turbine efficiency. The simulation is carried out at different velocities. The graphs are plotted between the maximum theoretical efficiency and wind velocity. These graphs are shown in fig 2. As shown in the graphs the maximum theoretical efficiency of the turbine blade twisted at a 0° angle varies from 0.67 to 0.84. The efficiency increases with inlet velocity and after sometimes remain constant. The maximum theoretical efficiency of the turbine with a blade twisted at a 45° angle shows a different pattern, its maximum theoretical efficiency varies from 0.78 to 0.92. The efficient first decrease with the inlet velocity, but after some time it increases and then remains constant. The maximum theoretical efficiency of the turbine with blade twisted at 90° mostly remain constant at all inlet velocities and ranges from 0.79 to 0.83. The maximum theoretical efficiency of the turbine with a blade twisted at 180° performs better at low inlet velocity, its efficiency increases with inlet velocity but after some time decreases and then remain constant. Its efficiency varies from 0.84 to 0.91.

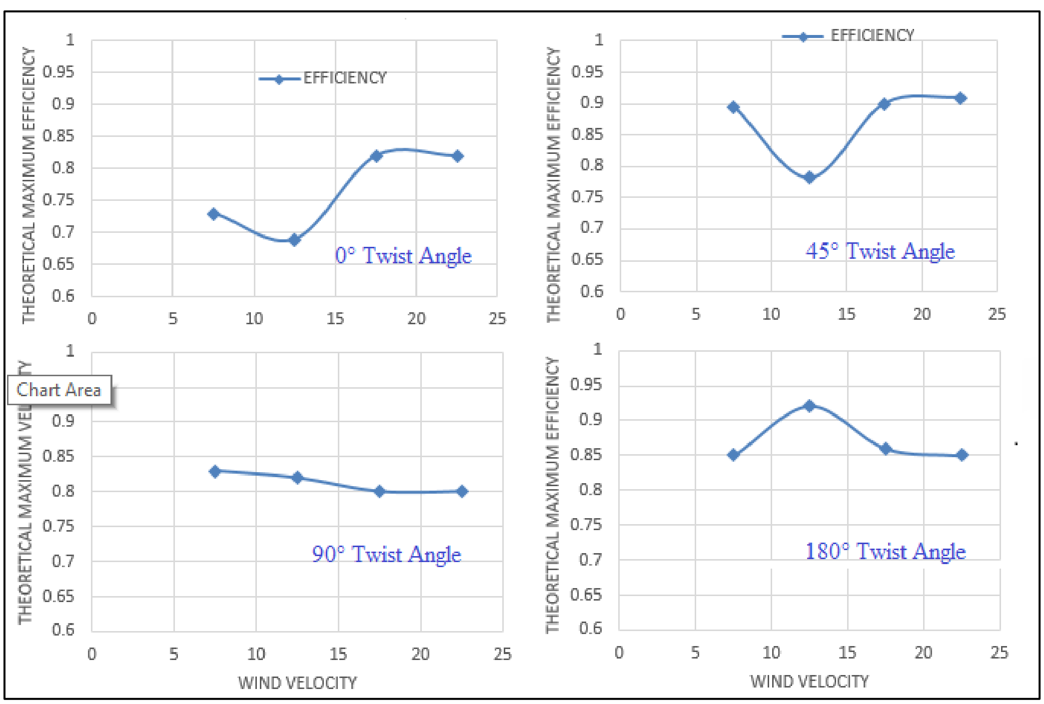

Fig. 2

V. CONCLUSION

After calculation and comparison of the maximum theoretical efficiency for all four types of turbine blades. It is concluded that the savonius wind turbine performs best at 45° twist angle. At this angle, the achievable maximum theoretical efficiency is comparatively higher and it increases with the wind velocity until it becomes constant. The savonius wind turbine with blades twisted at 45° works best with wind velocity ranges from 12 m/s to 20 m/s. Which is an optimal range of wind velocity for a vertical axis wind turbine. The savonius wind turbine with blades twisted at 180° works best with low-speed wind velocity. Its best working range of wind velocity is up to 12 m/s. This study also concludes that with an increase in twist angle the performance of the savonius wind turbine increases at low velocity. But at low-velocity turbine also generates less positive torque so less overall output.

ACKNOWLEDGMENT

Acknowledges support from our guide Prof. Neelam Baghel and the department of Mechanical Engineering of ITM Group of Institutions Gwalior.

REFERENCES

[1] Khandakar Niaz Morshed, Mosfequr Rahman, Gustavo Molina and Mahbub Ahmed “Wind tunnel testing and numerical simulation on the aerodynamic performance of a three-bladed Savonius wind turbine” International journal of energy and environmental engineering April 2013.
[2] Yudi Kurniawan, Dominicus Danardono Dwi Prija, Tjahjana and Budi Santoso “Experimental study of savonius wind turbine performance with blade layer addition” Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 69, Issue 1 (2020) 23-33.
[3] Suresh Talur, Kiran Kumar P and T Madhusudhan. “Review paper of savonius vertical axis wind turbine rotor blade” International open-access journal of modern engineering research (IJMER) March 2015.
[4] Rajat Gupta, R D Mishra and Bachu Dev “Performance analysis of a helical savonius rotor without shaft at 45° twist angle using CFD” Journal of urban and environmental engineering June 2013.
[5] Magdi Ragheb and Adam M. Ragheb “Wind Turbines Theory - The Betz Equation and Optimal Rotor Tip Speed Ratio” Fundamental and advance topic in wind power 2014.
[6] A. R. Jha, Wind Turbine Technology Book, Taylor and Francis group 2010.
[7] B. Wahyudi, S. Wahyudi and W. Denny “A Simulation study of flow and pressure distribution patterns in and around of tandem blade rotor of savonius (TBS) Hydrokinetic turbine model” Journal of clean energy technologies Vol. – 4 October 2013.
[8] A. A. Kadam and S. S. Patil “A review study on savonius wind rotor for accessing the power performance” IOSR Journal of mechanical and civil engineering (IOSR-JMCE) January 2013.
[9] Krzysztof Rogowski and Ryszard Maronski “CFD computation of the savonius rotor” Journal of theoretical and applied mechanics 53 pp. 37 – 45 Warsaw 2015.
[10] Wahyono Sapto Widodo, A. C. H. Sihombing and M. Y. Yuhazri “Design and analysis of 5 KW savonius rotor blade” Journal of Global engineer technology review Vol. – 2 Issue – 8 January 2012.
[11] Jae-Hoon Lee, Young-Tae Lee and Hee-Chang Lim “Effect of helical angle on the performance of savonius wind turbine” World Congress on Advance in civil, environmental and materials research (ACEM14) Busan Korea August 24 – 28, 2014.
[12] A. Vivek Anand et al. “Performance Augmentation of V-blade savonius turbine” International Journal of engineering and advanced technology (IJEAT) ISSN; 2249-8958, Vol. – 9 Issue – 2 December 2019.
[13] R. M. Khandagale and B. G. Marlapalle “Design and Analysis of savonius VAWt for 50W rated power output” International Journal of engineering research and general science Vol. – 5 Issue – 3 May – June, 2017.
[14] Ahmed S. Saad, Ali M. Abdel Salam, I. M. Sakr and W. A. El-Askry “Performance analysis of a helical savonius wind turbine with modified rotor” 17th International Conference on Aerospace sciences and technology ASAT – 17 April 11 – 13 2017.
[15] Mikhail Ramos D. and Daniel sauced C. “CFD study of a vertical Axis counter – rotating wind turbine” 6th International Conference on Renewable Energy research and Application, San Diego CA, USA, November 5 – 8, 2017.
[16] M. Zemamou, M. Aggour and A. Toumi “Review of savonius wind turbine design and performance” 4th International Conference on power and energy system engineering CPESE 2017 September 25 – 29 2017 Germany.
[17] Mohammed Hadi Ali “Experimental comparison study for savonius wind turbine of two and three blades at low wind speed” International Journal of modern engineering research (IJMER) Vol. – 3 Issue 5 Sep. – Oct. 2013.