Performance Analysis of Giromill Vertical Axis Wind Turbine with NACA 63618 Airfoil

Vaibhav H Davane[1], M L Thorat[2]

[1] *Research Scholar, Department of Mechanical Engineering, RMDSSOE Pune, Maharashtra, India-411058*
[2] *Assistant Professor, Department of Mechanical Engineering, RMDSSOE Pune, Maharashtra, India-411058.*

***

Abstract - *This project concerns with a Three Dimensional Simulation and experimental study into the aerodynamics and performance of Giromill type straight bladed Vertical Axis Wind Turbine (VAWT) with NACA 63618 airfoil and describes the effect of some design parameters including angle of attack, velocity of air and number of blades on the performance of them.*

Numerical simulation is done for three-dimensional steady flow around the Giromill VAWT model using ANSYS FLUENT. Shear-stress transport (SST) K-ω turbulence model was chosen to perform the transient simulations. Then, Giromill wind turbine model was manufactured and tested. Vast number of experiments was performed by changing air velocity from 2 m/s to 6 m/s with interval of 0.5 m/s for 0° and 180° angle of attack for four and six blades with airfoil NACA 63618.

The result shows that the wind turbine experienced maximum power coefficient of 30.49% and 33.89% for 3D simulations at 4.5 m/s wind velocity, 0° angle of attack for four blade and six blade respectively. The experimental results shows fair agreement with 3D ANSYS simulation results as maximum power coefficient obtained by experimentation was 25.11% and 27.90% at same conditions.

Keywords**: **Giromill VAWT, NACA 63618, Power Coefficient, SST K-ω turbulence model.

1. INTRODUCTION

Wind results from air in motion. Air in motion arises from a pressure gradient. The total kinetic energy of the wind in the lowest kilometer, if harnessed, can satisfy several times the energy demand of a country. It is also claimed that the wind power is pollution free and that its source of energy is free. Wind Turbine is a device used to convert the kinetic energy, also known as wind energy, available in wind into mechanical energy. The axis may be horizontal, as in the more familiar windmills, or vertical, as it is in some cases.

Though VAWTs have inherent advantages, HAWTs are dominant commercially. VAWTs have the great advantage of not having to be turned into the wind stream as the direction changes, because their operation is independent of wind direction. So, they do not need yawing equipment. They can require less structural support because heavy components like gear box and generator can be located at ground level. This configuration also eases installation and maintenance. Blades of VAWTs may be of uniform section and untwisted unlike HAWTs. So, fabrication of blades may be relatively easy. Probably the biggest disadvantage with VAWTs is that far less is known about them than HAWTs. This handicap is rapidly being removed. However, its high torque fluctuations with each revolutions, no self-starting capability are the other drawbacks. [1, 2]

Nahid Pervez and Wael Mokhtar presented flow characteristics around a VAWT using CFD tool. 2D, 3D, and simplified model of a VAWT for airfoil NACA4518 was simulated and results were presented [4]. Payam Sabaeifard et al. described Computational Fluid Dynamic and Experimental study on wind turbine and performance of small scale Darrieus type VAWT was evaluated. Also describes the effect of some design parameters on performance of VAWT [3]. An experimental and theoretical study of a prototype was performed for a 2.5 kW turbine using wind tunnel experimental data and CFD analysis by Bidgo et al., in which power curves have been developed at different wind speeds [6]. Raj Kumar and Ravindra studied the lift and drag forces in a wind turbine blade and the effect of angle of attack on the efficiency of wind turbine blade [7]. Howell et al. generated two and three dimensional unsteady CFD model to understand the aerodynamics of the performance. He concluded that performance predicted by two dimensional computation model is significantly higher than experimental and three dimensional CFD model [8].

Many wind turbine researchers were focused on accurately predicting efficiency. There were many computational models were available to find accurate performance of wind turbine. But, each model has its own strengths and weaknesses. This model analysis offers a possibility to reduce the number of experimental tests that are needed. Numerical prediction of performance is more economical than costly experimentation

2. SIMULATION OF GIROMILL VAWT

This paper evaluates the performance of straight bladed Giromill type VAWT with four and six blades using 3D steady flow analysis. In this analysis, NACA 63618 airfoil was used which is cambered airfoil. ANSYS 14.5 software was used to create 3D model of a turbine and for mesh.

In the present work, Moving Reference Frame (MRF) concept was used to carry out a series of steady state simulations at fixed turbine. In this case, two separate fluid flow domains have been created around the turbine. The flow domain has cylindrical shape. Out of these two cylinders of flow domain, outer cylinder is kept fixed, known as Stationary Fluid Domain (SFD) and inner cylinder was moving. The axis of inner cylinder was same as that of turbine and that for outer cylinder was perpendicular to turbine axis i.e. the wind turbine is enclosed in MRF coaxially and the MRF is surrounded by stationary fluid domain. Fig. 1 and Fig. 2 show the 3D ANSYS model of Giromill VAWT with airfoil NACA63618.

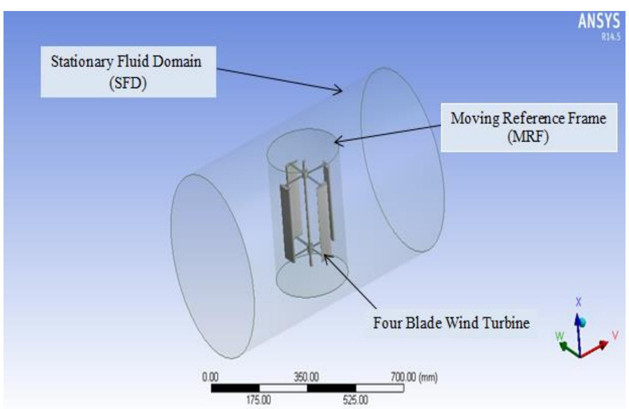

Fig. 1 3D ANSYS Turbine Model with MRF and SFD with Four Blades

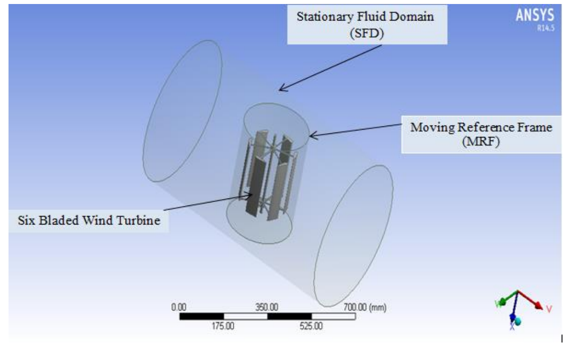

Fig. 2 3D ANSYS Turbine Model with MRF and SFD with Six Blades

The meshing strategy used in this work uses unstructured type grid. A tetrahedral type mesh has been applied to the total wind turbine model. Fig. 3-4 shows the various sections of meshed model of four and six bladed wind turbine.

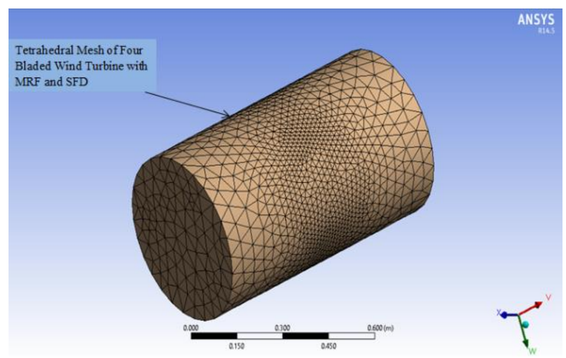

Fig. 3 Section of Meshed turbine model placed in MRF and SFD of Four Blade VAWT

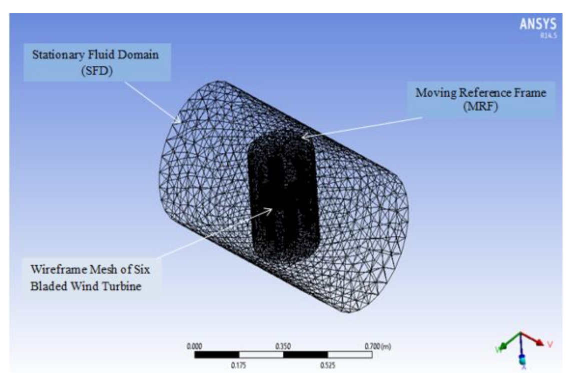

Fig. 4 Section of Meshed turbine model placed in MRF and SFD of Six Blade VAWT

Mesh metrics available in ANSYS Meshing include: Element Quality, Aspect Ratio, Jacobian Ration, Warping Factor, Parallel Deviation, Maximum Corner Angle, and Skewness.

Table-1 Details of Meshing

Parameter	Four Bladed	Six Bladed
Growth Rate	1.2	1.2
Aspect ratio	1.988	2.273
Total number of	342035	450462
Total number of Elements	2036936	2686223

The Solver used was Pressure based absolute velocity with steady time. Three cell zones were created viz., Turbine, Moving Reference Frame and stationary flow domain. Inlet velocity of air was varied from 2 m/s to 6 m/s. Outlet pressure was kept constant at 0 Pascal.

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1 Wind Turbine Design

The used Giromill wind turbine model has the following components and parameters:

Shaft: The shaft used is made of stainless steel (SS 314) with diameter of 14 mm and length 285 mm.

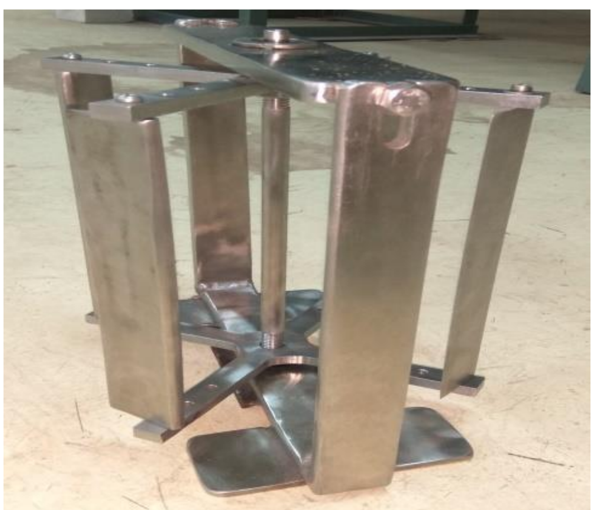

Fig. 5 Prototype of Four bladed VAWT

Fig. 6 Prototype of Six Bladed VAWT

Blades: The airfoil blades used are manufactured according to NACA 63618 specifications. The material used is SS 314. The chord length of the blades is 40 mm and the span length is 220 mm. These blades are mounted and fixed to the spoke of the supporting link by bolts.

Rotor Cage: A rotor was designed to hold the airfoil blades on the turbine, each turbine needing 2 cages- one at the top and one at the bottom- to hold the blades. The variation of the number of blades was achieved by designing 2 rotors i.e. one for a 4-bladed turbine and another for a 6-bladed turbine. The material used for these links is stainless steel. The main function of these links is to transmit the power from blades to shaft.

Bearings: The bearings used are; two deep groove ball bearings (SKF-6200-2Z/C3) with inner diameter 10 mm and outer diameter 30 mm. These bearings permit the relative motion between the turbine shaft and the supporting frame. One bearing is placed at the top side of the frame while the other at the bottom side.

Supporting frame: The main function of the supporting frame is to support the turbine assembly. The dimensions of the frame were chosen according to the test section. The main model was clamped to this arrangement.

3.2 Wind Tunnel Setup

The wind tunnel is of suction type with an axial flow fan driven by an AC motor connected to a variable frequency drive. The wind tunnel is divided into 3 sections viz. Suction side, Test section, and discharge side.

Fig. 7 Experimental Setup

3.3 Insrumentation

Digital Tachometer: Digital tachometer is used to measure the turbine speed (rpm) with an accuracy of ±1%.

Pitot Tube : A pitot tube is a pressure measurement instrument used to measure fluid flow velocity. It is widely used to determine the air speed of an aircraft, water speed of a boat, and to measure liquid, air and gas flow velocities in industrial applications.

4. RESULT AND DISCUSSION

4.1 ANSYS Simulation Results and Discussion

The 3D analysis is performed to characterize the performance of Giromill type Vertical Axis Wind Turbine. The following curves describe the comparisons of the performance of some variations resulting from changing parameters like velocity of inlet air, angle of attack and number of blades. Simulation is done by increasing inlet air velocity from 2 to 6 m/s with increment of 0.5 m/s for 0° and 180° angle of attack for two and four blade VAWT.

1)Effect of Velocity of inlet air on performance of VAWT

Fig. 8- 11describes the effect of tip speed ratio on torque and coefficient of power of wind turbine for four blade and six blade wind turbine.

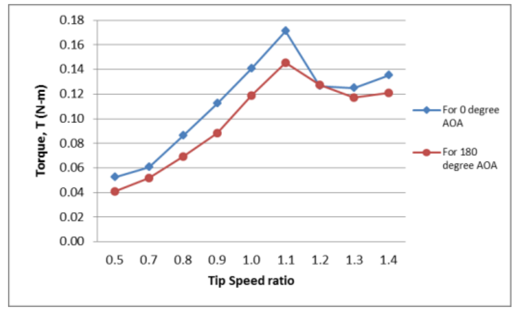

Fig. 8 Effect of Tip Speed Ratio on Torque for constant AOA with four blade wind turbine

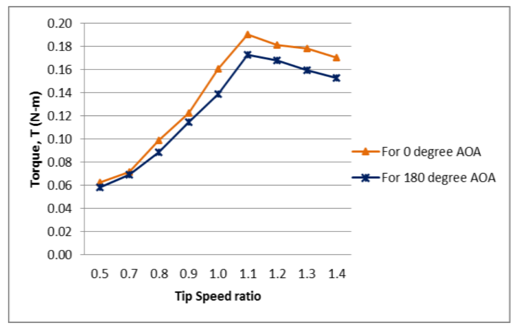

Fig. 9 Effect of Tip Speed Ratio on Torque for constant AOA with six blade wind turbine

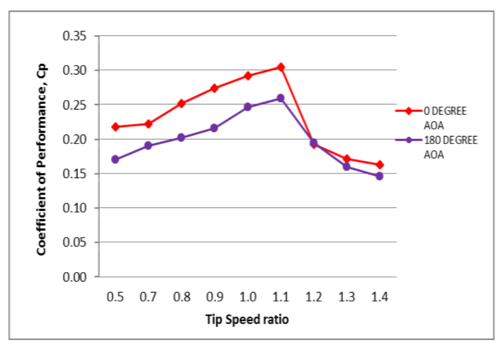

Fig. 10 Effect of Tip Speed Ratio on Coefficient of Power for constant AOA with four blade wind turbine

It is observed that for four bladed wind turbine the peak value of coefficient of power for each angle of attack is at tip speed ratio of 1.1397. As the velocity of air increases, the rotor rpm increases and hence power drawn by turbine also increases; but after peak value, if velocity of air is increased then power drawn by turbine is decreased. This sudden decrease in power drawn from turbine is called as **STALLING.** Also, it is clear that six blade wind turbine gives highest performance at 1.1397 tip speed ratio for both angles of attack.

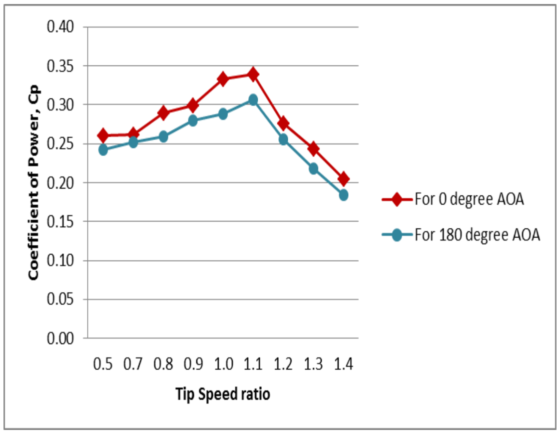

Fig. 11 Effect of Tip Speed Ratio on Coefficient of Power for constant AOA with Six blade wind turbine

The maximum coefficient of power for four blade wind turbine is 0.3049 which is obtained at 4.5 m/s inlet air velocity with 0° angle of attack and for six blade wind turbine is 0.3389 which is obtained at 4.5 m/s inlet air velocity with 0° angle of attack.

2) Effect of Angle of Attack on Performance of VAWT

From fig. 8-11, it is also clear that turbine draws maximum torque at 0° angle of attack as compared to 180° angle of attack. Also, maximum coefficient of power is obtained at 0° angle of attack.

3) Effect of Number of Blades on Performance of VAWT

Fig. 8-11, shows the effect of number of blades on coefficient of power for 0° angle of attack and fig. shows the effect of number of blades on coefficient of power for 180° angle of attack.

4.2 Experimental Result and Discussion

The manufactured model of Giromill Vertical Axis Wind Turbine with NACA 63618 airfoil is tested in wind tunnel for different values of angle of attack, velocity of inlet air and number of blades. Following plots are produced on the basis of experimental results.

1) Effect of Velocity of Inlet air on Performance of VAWT

Fig. 12-13 shows the effect of Tip Speed Ratio on experimental torque for four and six blade wind turbine respectively.

The nature of plots of experimental power coefficient is similar to that of ANSYS Simulation results i. e. as tip speed ratio increases value of torque and therefore power coefficient increases up to specific limit and then starts decreasing. From Fig. it is clear that as the velocity of air increases up to 4.5 m/s, the coefficient of power increases and after that increase in air velocity leads to decrease in power coefficient.

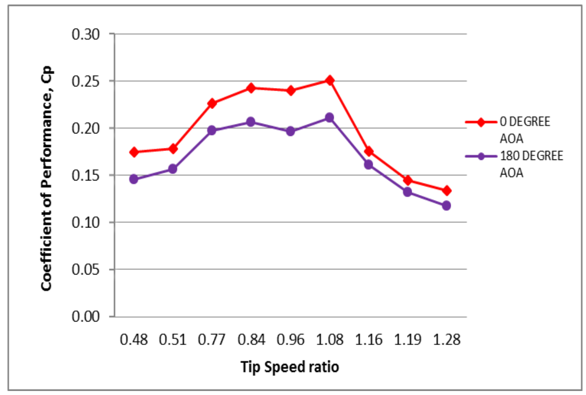

Fig. 12 Effect of Tip Speed Ratio on Coefficient of Power for constant AOA with four blade wind turbine

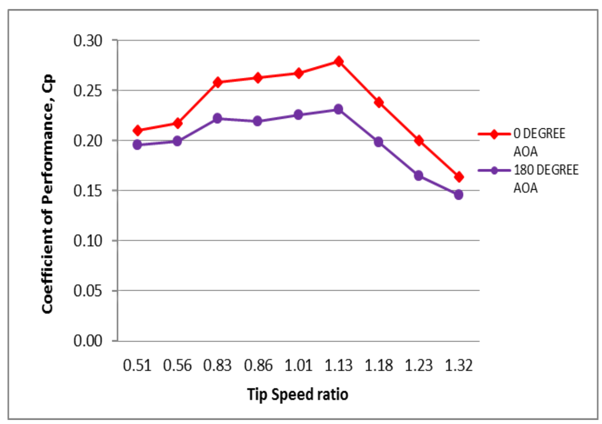

Fig. 13 Effect of Tip Speed Ratio on Coefficient of Power for constant AOA with six blade wind turbine

4.3 Comparison between ANSYS Simulation and Experimental Results and Discussion

Fig.14-17 shows the comparison between the ANSYS Simulation results and Experimental results for four blade Giromill Vertical Axis Wind Turbine for 0° and 180° angle of attack.

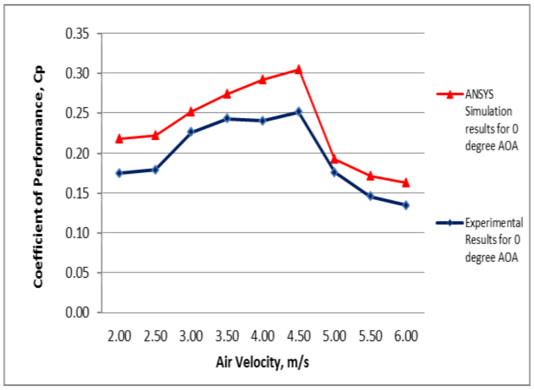

Fig. 14 Comparison between ANSYS Simulation and Experimental Results for 0° AOA for Four Bladed Wind Turbine

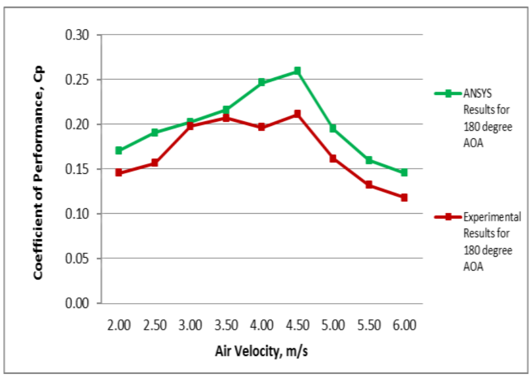

Fig. 15 Comparison between ANSYS Simulation and Experimental Results for 180° AOA for Four Bladed Wind Turbine

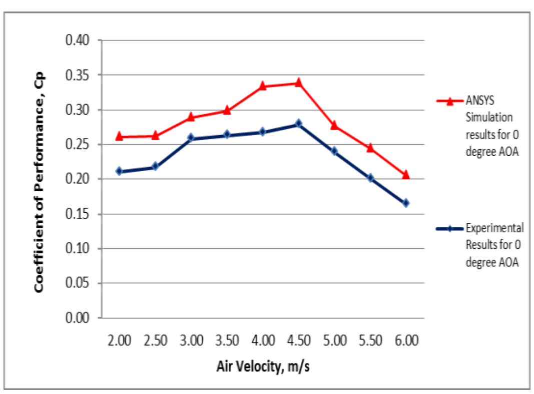

Fig. 16 Comparison between ANSYS Simulation and Experimental Results for 0° AOA for Six Bladed Wind Turbine

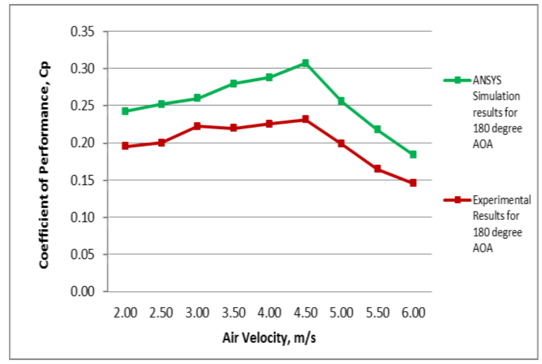

Fig. 17 Comparison between ANSYS Simulation and Experimental Results for 180° AOA for Six Bladed Wind Turbine

From Fig. 14-17, it is concluded that the performance coefficient predicted by the three dimensional computational model is significantly higher than that of the experimental model. There is reasonable agreement in both the level and the shape of the 3D predictions and the experimental measurements, which gives confidence that the 3D ANSYS Simulation is correctly capturing the essential flow physics of the aerodynamics. From Fig. 14-17, it is observed that at lower and higher tip speed ratio the difference between 3D ANSYS Simulation results and experimental results is higher as compared to the middle tip speed ratio. The reason behind that is at low velocity of air, turbine blades cannot draw maximum power from wind and; at high velocity of air, mechanical losses are more. So, actual power extracted from wind is less as compared to 3D ANSYS Simulation.

It is observed that the error obtained between 3D ANSYS Simulation and experimental results is in the range of 2 to 24%. It is concluded that at lower angle of attack minimum error is occurred while at higher angle of attack maximum error is occurred.

Following type of losses and inefficiencies occurred in the operation of wind turbine: Whirlpool losses, end losses, blade number losses, airfoil profile losses, and frictional losses in bearings etc.

The overall difference between the predicted 3D ANSYS Simulation performance and the experimental results is believed to be caused by a number of reasons.

5. CONCLUSION

Based on the research work, the aims and objections of the research project have been achieved. The significant findings are summarized below.

1. The angle of attack, number of blades and velocity of air has significant effect on torque, coefficient of power. There is an optimum ambient wind speed for each angle of attack at which the maximum efficiency is achieved.
2. It is seen from the numerical as well as experimental study that performance of six-bladed design is more efficient than a four-bladed rotor.
3. The maximum power coefficient obtained in this research is **0.3389** using an angle of attack 0°, velocity of air 4.5 m/s with six blades which is found to be the best configuration in this study by 3D ANSYS Simulation. Also, for experimental analysis maximum power coefficient obtained is **0.2790** using an angle of attack 0°, velocity of air 4.5 m/s with six blades.
4. Computational predictions of the performance coefficient of this turbine are carried out and the 3D simulations are shown to be in reasonably good agreement with the experimental measurements, considering errors and uncertainties in both the 3D ANSYS simulations and the wind tunnel measurements. ANSYS-Fluent shows a good performance in calculating coefficients of airfoils when compare to the experimental data.

REFERENCES

[1] G. D. Rai, *Non-Conventional Energy Sources*. Khanna Publishers, Fourth Edition, ISBN No. 81-7409-073-8, 2008, Delhi, pp. 225-310.
[2] R. Mittal, K. S. Sandhu, D. K. Jain, "An overview of some important issues related to wind energy conversion system," *International Journal of Engineering Science & Development;* 2010, 1(4), pp. 351-363.
[3] S. Payam, R. Haniyeh, F. Ayat, "Determination of Vertical Axis Wind Turbines Optimal Configuration through CFD Simulations," *International Conference on Future Environment and Energy*, vol.28, 2012.
[4] N. Pervez, W. Mokhtar, "CFD study of a Darrieus VAWT," *ASEE North Central Section Conference*, 2012.
[5] G. Colley, R. Mishra, H. V. Rao, R. Woolhead, "Performance evaluation of 3 cross flow Vertical Axis Wind Turbine configuration," *Proceeding of Computing and Engineering Annual Researchers conference*, 2009, ISBN-9781-8621-80-857, pp. 130-136.
[6] A. M. Bidgo, A. Simonovic, D. Kamarov, S. Stupar, "Numerical and Analytical Investigation of Vertical Axis Wind Turbine," FME Transactions, 41, 2013, pp. 49-58.
[7] S. Rajakumar, D. Ravindran, "Computational Fluid Dynamics of wind turbine blade at various angles of attack," *International Journal of Engineering Science & Technology*, 2010, 2(11), pp. 6474-6484.
[8] R. Howell, N. Gin, J. Edwards, N. Durrani, "Wind Tunnel and Numerical Study of a Small Vertical Axis Wind Turbine," Renewable energy, 2010, 35(2), pp. 412-422.
[9] C. Kaminsky , A. Filush, W. Mokthar, K. Paul, "A CFD study of Wind Turbine Aerodynamics," *Proceedings of the 2012 ASEE North Central Section Conference*,2012.
[10] A. A. E. Ghorab, Samanoudy, Z. Yousf, "Effect of some design parameters on the performance of a Giromill VAWT," *Ain Shams Engineering Journal*, 2010, 1, pp. 85-95.
[11] S. Eriksson, H. Berhoffs, "Evaluation of different turbine concepts for wind turbine, Renewable & Sustainable Energy Reviews," 2008, 12, pp. 1419-1434.
[12] P. Sabaeifard, R. Razzaghi, A. Forouzandeh, "Determination of vertical axis wind turbines optimal configuration through CFD Simulations," *International Conference on Future Environment and Energy, Singapore,* 2012, IPCBEE, 28(2012).
[13] J. Kjellin, F. Bulow, S. Eriksson, "Power coefficient measurement on a 12 kw straight bladed VAWT," Renewable Energy, 2011, 36, pp. 3050-3053.
[14] J. Yao, H. Wang, W. Yuan, Z. Wang, L. Cao, "Analysis on the influence of Turbulence Model changes to Aerodynamic performance of Vertical Axis Wind Turbine," *Procedia Engineering,* 2012, 31(2012), pp. 274-281.
[15] F. Bulow, "Extreme Load Conditions for Wind powered Direct Drive PM Generators," Uppsala University, UURIE, 2011, pp. 324.