Numerical Analysis of Multistory Vertical Axis Wind Turbine

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Abstract: This paper aims to study the performance of multistory vertical axis wind turbine.The said turbine will be used for generation of power for domestic use. The coefficient of power of the turbine is measured at different tip speed ratio and angle of attack. Computational fluid dynamics is used to obtain power coefficient of Multi story vertical axis wind turbine. In this analysis, K-ω SSTturbulence model andmoving reference frameapproach has been used. It has been found that maximum lift force is obtained at 30^0 angle of attack, maximum drag force is obtained at 60^0 angle of attack and maximum pressure difference and maximum Cp is obtained at120^0 angle of attack.

Keywords: Vertical axis wind turbine, Multi story, power coefficient, Computational fluid dynamics.

Nomenclature:

A rotor swept area(m^2)	ω angular speed (rad/s)
Cp power coefficient	TSR tip speed ratio
D rotor diameter(m)	ρ air density(kg/m^3)
N rotor rotational speed (rpm)	σSolidity ratio
P rated power(W) *CL*	Lift coefficient
T torque (N-m) *CD*	Drag coefficient
a Axial induction factor	β angle of relative wind (°)
r radius of rotor(m)	

1. INTRODUCTION

Wind energy is readily available throughout 24 hrs, which can be exploited for power generation. Vertical axis wind turbines (VAWT) arepreferred over Horizontal axis wind turbines (HAWT) when it comes to domestic use.Though VAWTs are less efficient as compared to HAWTs, the cost effectiveness is quite good for individual users as supplementary energy generators or at remote locations as standalone energy source. There is need for development of more efficient and stable VAWT. In this paper an innovative concept of Multistory Vertical Axis Wind Turbine (MVAWT) have been proposed to improve the performance of wind turbine in terms of power coefficient, stability. Numerical Analysis of the turbine is required to be done to evaluate the performance. Computational Fluid Dynamics (CFD) has the capability of solving momentum equation, energy equation governing the fluid flow using numerical means. By creating sufficiently refined grid, the solution of discretized governing equation yields a flow that is reasonably representation of real time situation.In this paper CFD has been used for computing torque and power coefficient of innovative Multistory Vertical Axis Wind Turbine (MVAWT).

Amano and Malloy had designed wind turbine blade which gives maximum efficiency at low speed and analyzed by using CFD [1]. Sabaeifard and Razzahianalyzed the effect of some design parameters on the performance of wind turbine [2].Pervezand Moktharsimulateda H rotor Darrieus rotor at different angle of attack and speed to measure the lift coefficient. [3]Jonathan reviewed the development of CFD as applied by the wind energy community from small scale to large scale from the flow around 2D airfoil to the flow through entire wind farm[4].Ivan and Massohstudied the behavior of a Savonoius wind turbine under flow field condition and to determine its performance and evolution of wake geometry[5].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[6].Howell et.al generated two and three dimensional unsteady computational fluid dynamics (CFD)model to understand the aerodynamics of the performance . He found that performance predicted by two dimensional computation model is significantly higher than experimental and three dimensional CFD model [7].Pope et.al conducted numerical and experimental studies to determine the power output of Zephyr vertical axis wind turbine at constant and variable rotor velocities [8].

To improve the aerodynamic performance of the VAWT, an innovative Mutistory vertical axis wind turbine is designed and developed. The objective of this paper is to evaluate the performance this turbine for different tip speed ratio and angle of attack.

2. DESIGN SPECIFICATION

In a quest to have enhanced performance of VAWT, an innovative Multistory Vertical Axis Wind Turbine has been developed. The wind turbine is made of multiple story in view to harness maximum wind energy available in the wind. Care has been taken to keep the slack time up to its minimum during every rotation of the turbine rotor. The dimensions of the prototype were governed by the test section dimensions of the wind tunnel. The turbine specification is given as follows.

Sr No	Part	Specifications	Sr No	Part	Specifications	Sr No	Part	Specifications
1	Blades	6nos	4	Rotor radius	0.1 m	7	Total Height of turbine	0.218 m
2	NACA aerofoil	68-613	5	Height of blade	0.07 m	8	Plate diameter	0.2 m
3	Solidity	0.49	6	Height of flap	0.07 m			

3. BLADE ELEMENT MOMENTUM METHOD IS USED FOR CALCULATION OF TORQUE.

$$dFx = \frac{\sigma\pi\rho V^2(1-a)^2 \; (CL \sin\beta + CD \cos\beta) rdr}{\cos^2 \beta} \qquad \text{(i)}$$

$$dT = \frac{\sigma\pi\rho V^2(1-a)^2 \; (CL \cos\beta - CD \sin\beta) r2dr}{\cos^2\beta} \qquad \text{(ii)}$$

The power coefficient Cp which represented the ratio of obtained power to available power in wind.

Power available in wind = $0.5\rho \, V^3 \, A$

$$Cp = \frac{Pactual}{0.5\rho \, V^3 \, A} \qquad \text{(iii)}$$

4. CFD SIMULATION

ANSYS 14.5 has been used for complete analysis of wind turbine. Using CFD simulation torque and pressure on the turbine rotor is predicted. The 2 D geometry of Multistory Vertical Axis Wind Turbine has been created by using preprocessor Design Modular.

To perform the dynamic simulation, Moving Reference Frame (MRF) capability of CFD solverhas been used which allows to model problems involving moving parts. The Moving reference frame is activated in selected zone,that modifies the equation of motion with additional acceleration terms which occurs due to transformation from stationary to Moving Reference Frame.

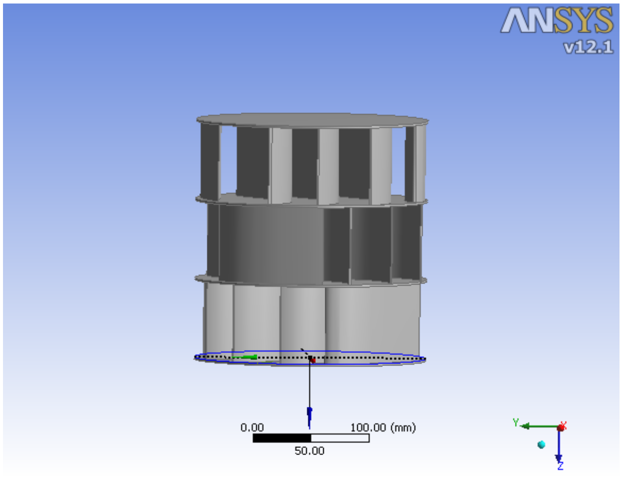

Fig No. 1 Geometry of three story VAWT

By solving the equations in steady state manner, the flow around the moving part is modeled. The moving reference frame does not account for the relative motion of a moving zone with respect to adjacent zones. Thus the mesh remains fixed for computation. The turbine is enclosed in MRF coaxially. The MRF is enclosed in a computational flow domain. The flow domain is having cylindrical shape. It was extended in axial direction about 4 diameters upstream and 8 diameters downstream of the rotor. This was to make sure that air fully extended. The fluid flow domain diameter is twice the diameter of the rotor. The left side of the domain is named as velocity inlet. The blockage ratio is kept minimum to bring the simulation close to field testing.

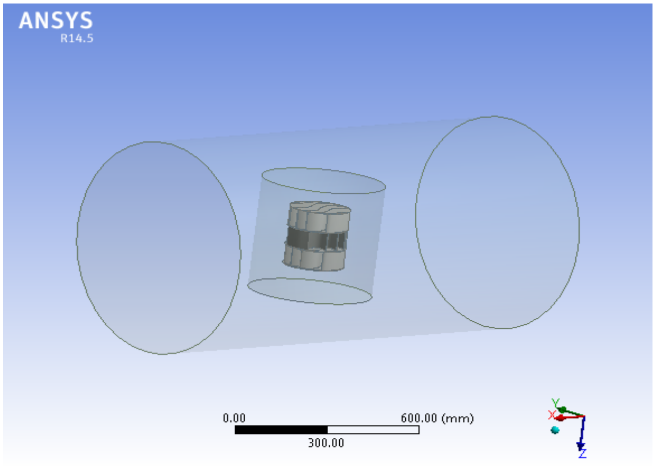

Fig no 2: Turbine model placed in Moving Reference Frame and Stationary Computational Domain.

Meshing is unstructured with growth rate of 1.2.The skewness is 0.2528 and the aspect ratio is 1.988.The total number of nodes is 1, 81,665.All the computations were done in ANSYS FLUENT 14.5. The solver used was Pressure based, absolute velocity with steady time. K-ωSSTturbulence model with standard wall function is used. Cell zones created are turbine, MRF and Computational flow domain. Inlet velocity is varied in the range of 9- 11 m/sec. The pressure at the outlet is kept 0 Pascal. The turbine and MRF wall is considered as moving wall with rotational velocity along Z axis with no slip.

5. CFD RESULTS & DISCUSSION

In this paper aninnovative MultistoryVertical Axis Wind Turbine with NACA 68-613 is designed and analyzed for different tip speed ratio at different angle of attack ranging from 0^o-180^o. The wind turbine rotational speed varies from 900-1100 rpm [5]. Torque is calculated for different angle of attack and tip seed ratios.

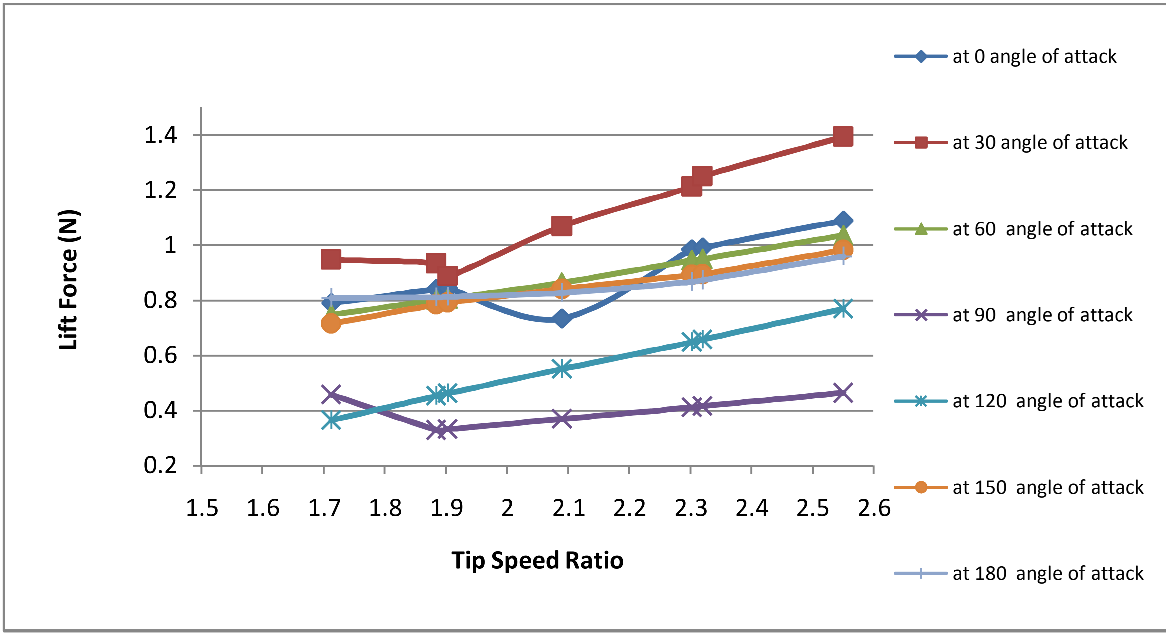

Fig no 4: Plot of lift force vs. tip speed ratio for different angle of attack.

Lift force is maximum for tip speed ratio 2.55 for 30 ^{0} angle of attack and minimum at tip speed ratio of1.81 for angle of attack 90 ^{0}.As the angle of attack increases from 0 ^{0} to 30 ^{0} the air gets deflected to a larger angle which increases the vertical component of the air stream .Thus maximum lift is obtained. Increasing the angle of attack further, it is seen that the air becomes turbulent and starts separating from the blades.

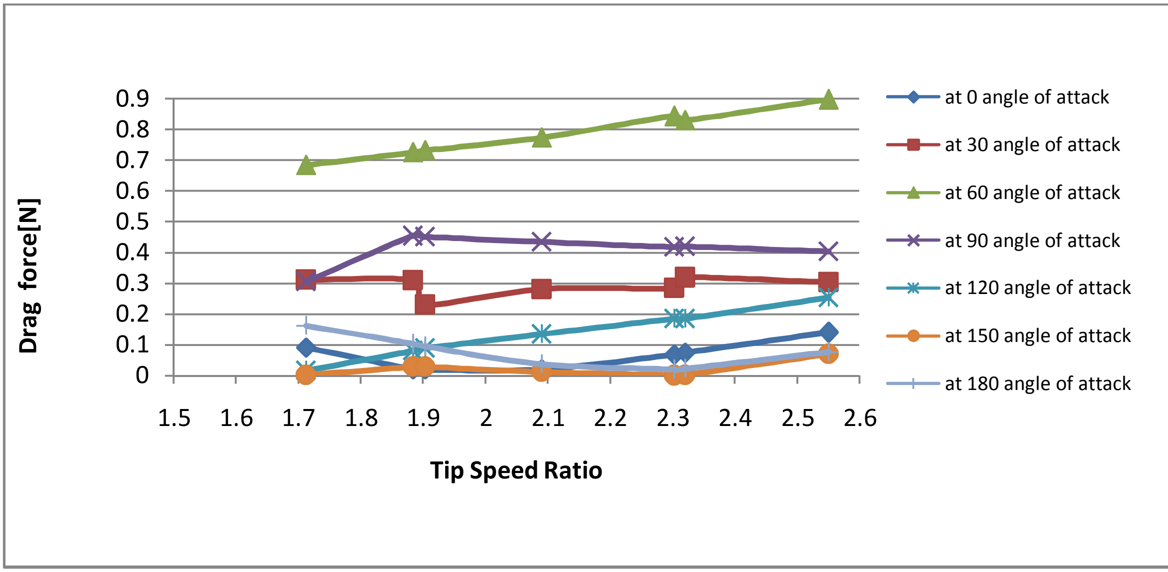

Fig no 5: Plot of Drag force vs Tip speed ratio for different angle of attack.

Drag force is maximum at 2.55 tip speed ratio and 60 ^{0} angle of attack and minimum at 1.7 tip speed ratio and 150 ^{0} angle of attack. The reason for increase in drag force is due to formation of vortices.

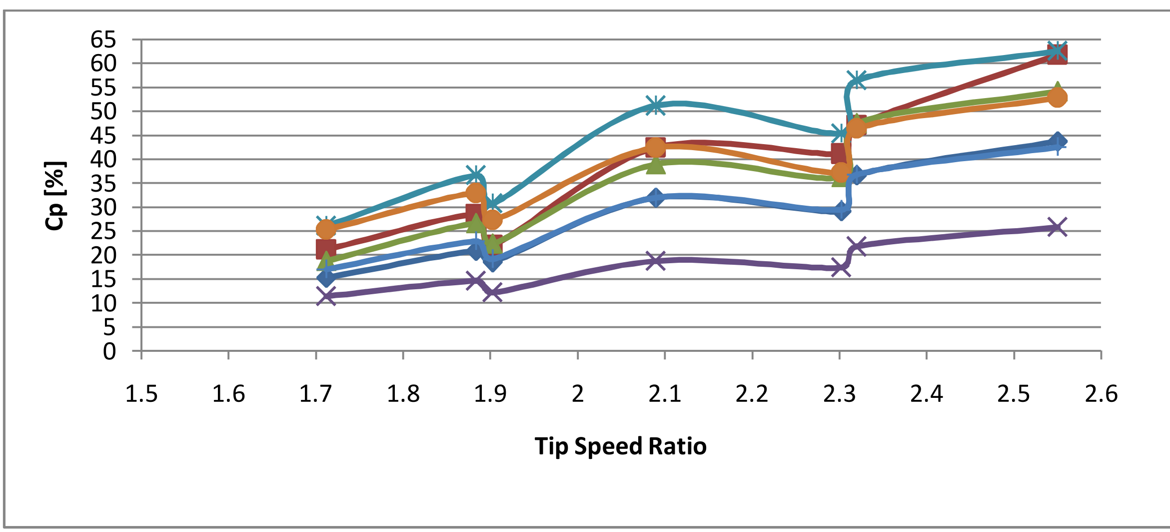

Fig no 6: Plot of CpVs Tip sped ratio for different angle of attack

The Coefficient of Power is maximum for Tip speed ratio 2.55 and angle of attack 120^{0}. The power generated is more due to maximum pressure difference.

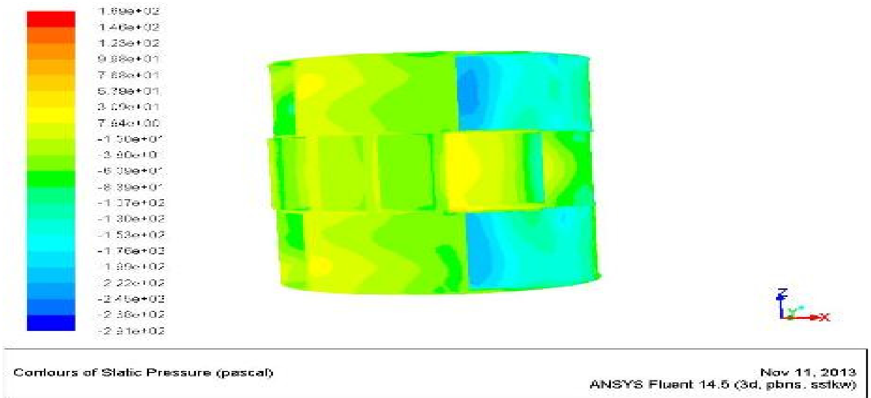

Fig no 8: Static pressure plot of M VAWT at 0^{o} angle of attack

6. CONCLUSION

The CFD analysis of Multi story Vertical Axis Wind Turbine has been made. It has been very predominantly observed that moment generated by the flow in the Moving Reference Frame for MSVAWTis maximum for tip speed ratio 2.55 for angle of attack 120^{o} .The Coefficient of power is minimum for 90^{o} angle of attack at tip speed ratio of 1.9. This is because of minimum pressure difference. The Lift force is maximum for tip speed ratio 2.55 for angle of attack 30^{o}and minimum for angle of attack 90^{o}at tip speed ratio 1.9.The drag force is maximum for tip speed ratio 2.55 for angle of attack 60^{o}and minimum for angle of attack 150^{o}at tip speed ratio 2.3.Static pressure plots it is seen that the pressure on of the leading edge of turbine blades and flaps is maximum. Pressure goes on reducing as it goes to the trailing edge. Minimum static pressure is seen on the trailing part of the turbine.

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