Numerical Analysis of the Aerodynamic Characteristics of an Archimedes Wind Turbine Blade for varying Pitch angle

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Abstract - *In the wind turbine industry the conventional HAWTs and VAWTs like Savonius, Darrieus etc. are the most used type of wind turbines used in large scale power production. The Archimedes wind turbine is an unconventional type of horizontal axis wind turbine that is based on the Archimedes spiral. It operates on relatively low wind speeds at high efficiency. Designed for low level power production it is very much feasible to use in rooftops of urban households and skyscrapers.*

Analysis was done for varying pitch angle models of the Archimedes spiral wind turbine. The CFD analysis implements a Standard K Omega Model and also implements Sliding mesh technique for Dynamic mesh effect for the rotating turbine blade. On evaluating the results from the CFD analysis it was found that maximum torque was obtained for a pitch angle of 50^o.

Key Words: CFD (Computational Fluid Dynamics), HAWT (Horizontal Axis Wind Turbine), PIV (Particle image Velocimetry) , Sliding Mesh Technique, VAWT (Vertical Axis Wind turbine)

1. INTRODUCTION

In a world plagued by the harmful and toxic emission from burning of fossil fuels and industries since the dawn of industrialization and also a call for cleaning up earth of the ever increasing quantities of human wastes that do not decompose, the need for renewable energy sources are very much stressed upon now to reduce the pollution levels produced by the power sector. The global greenhouse gas quantity in the atmosphere is ever increasing so the global community is calling on for a reduction in the production and consumption of crude oil. Among the top contenders for renewable energy sources: solar energy, wind energy, tidal energy and geothermal energy are conventionally most used. These energy sources produce very little or no emissions.
In the present case scenario the wind energy is mainly focussed on the production of large scale wind energy production using mainly HAWTs and VAWTs.

The conventional VAWTs consist of various designs including Savonius and Darrieus. VAWTs are Omni directional and have a direct drive but the reason why VAWTs are less preferred is that there persists the problem of less efficiency and reliability. Generally VAWTs quote noise levels of less than 40 dB at a distance of less than 20 ft/6m, while fewer HAWT models are present that offer such measurements often report 50 to 60 dB or more at much greater distances. As compared to HAWTs, VAWTs are generally more compact and operate at smaller elevations, making them less visually obstructive. However, VAWTs might have issues, some say, with reliable self-start in lower wind speeds and with less efficient power production than HAWTs (the low rotation speeds are quiet but not quite efficient).

HAWTs are the most commonly used kind of wind turbines. It is preferred due to a number of reasons like variable blade pitch which can give an optimum angle of attack to the wind turbine blades, taller towers giving them access to higher heights and thus consequently higher winds and higher efficiency since the blade rotates perpendicular to the direction of the wind thus giving power throughout the rotation whereas VAWTs have to back track a part of the rotation thus causing it to lower its efficiency. The HAWTs have a lot of downsides to it such as transporting the tall towers(including the shafts and the blades) is very difficult and drives up the transportation charges monumentally, very strong supports are required to support the tower assembly and also require an additional mechanism to turn the turbine according to the wind direction.

Small scale wind turbine designs that are generally used are the scaled models of the HAWTs and even some VAWTs like Savonius and Darrieus models. Small scale wind turbines find applications in small public power usage equipment like street lights which are run by individual wind turbines augmented with an auxiliary power source from a battery which supplies the power when the wind speeds are low or negligible. Small scale wind farms can be setup on top of skyscrapers which have relatively higher wind speeds.

2. NUMERICAL MODEL

2.1 Physical Geometry

The numerical simulation was done in Fluent Ansys 15.0 with the turbine model being imported into the geometry section of the Fluent tab. The grid independence study was done for the simulation model with the torque value being the tested parameter. The numerical analysis is done as a transient simulation which employs a pressure based solver. The turbulence model adapted in this case is Standard K Omega model. In the cell zone condition under the "Mesh

Motion" the rotational part is given a rotational speed of 300 rpm which is derived from the experimental results for doing the validation. In the boundary condition section the "Inlet" is defined as a Velocity Inlet and given a velocity 3.5 m/s (from experimental observation) and the Outlet is defined as a Pressure Outlet. A UDF (User Define Function) is defined to identify the 6DoF (Degrees of Freedom) and assign properties like mass and MoI (Moment of Inertia.

The Archimedes spiral is defined as

$$r = a + b\theta^c$$

where a, b, c are real numbers and c = 1 for normal Archimedes spiral.

r= radius of spiral

θ=angle in radians

Converting to Cartesian coordinates - :

$$x = r \times \cos t \Rightarrow (740/(2 \times \pi) \times t+10) \times \cos(t)$$

$$y = r \times \sin t \Rightarrow (740/(2 \times \pi) \times t+10) \times \sin(t)$$

$$z = 1100 \times t/2\pi$$

value of t varies from π to 2π

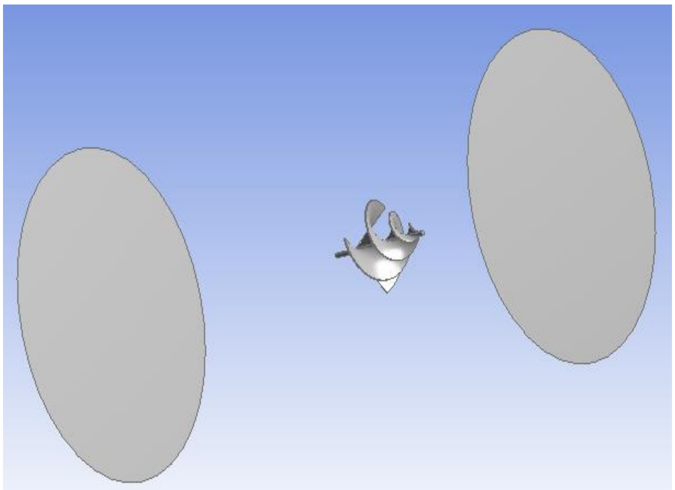


Fig.-1 Ansys simulation geometry

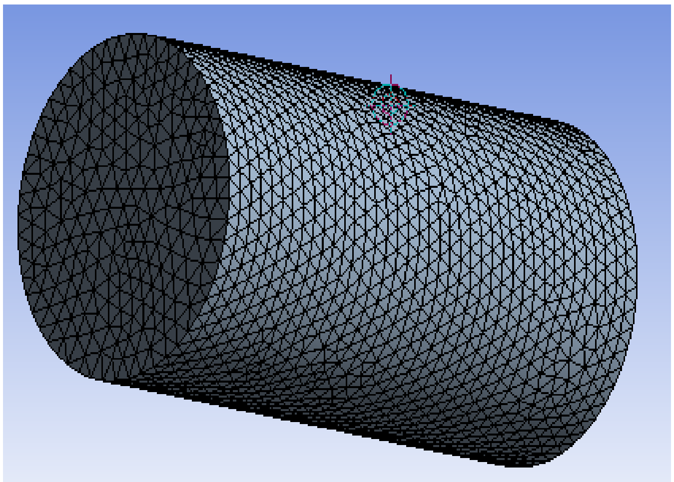


Fig. -2: Meshing

2.2 Model Validation

The experimental values from the research done by Kyung [1] provides PIV related flow data to which the numerical model was validated. The values that were taken into account was Velocity Magnitude for 4 different velocity profiles for which 4 different validation curves were plotted.

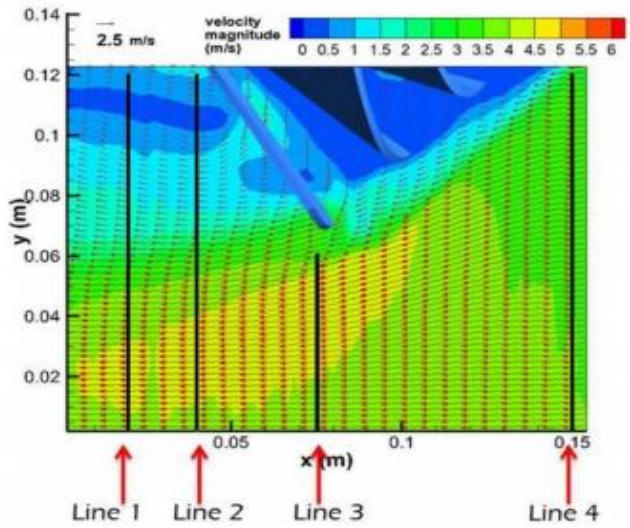
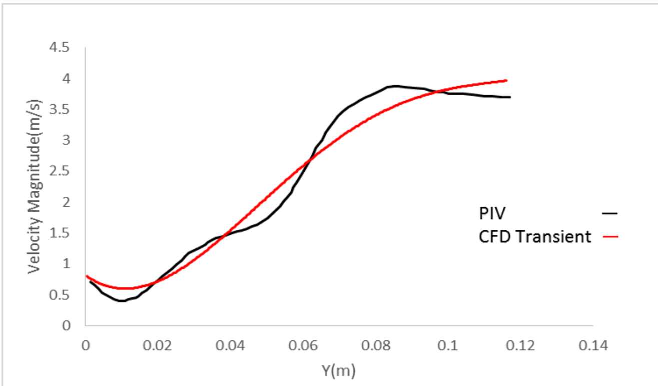
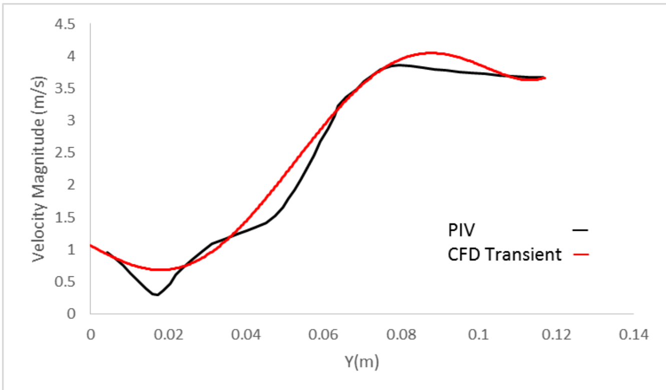


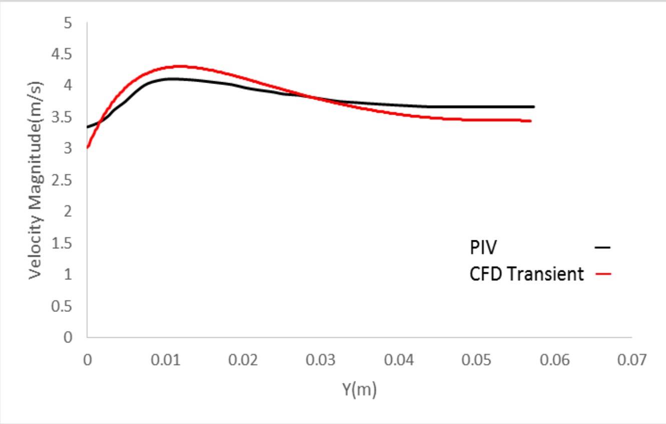
Fig -3 : Comparison of CFD transient and PIV values



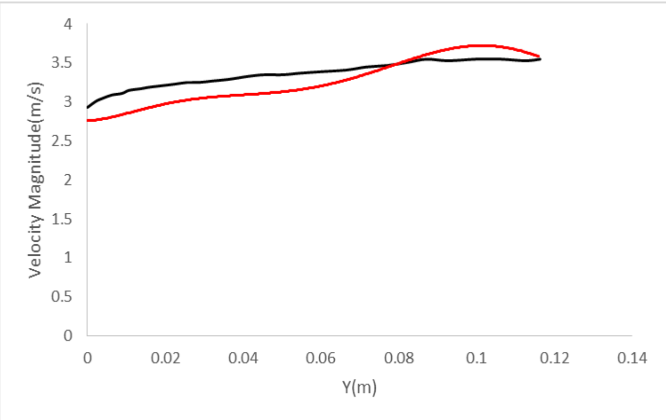
a) Velocity Profile for Line 1



b) Velocity Profile for Line 2



c) Velocity Profile for Line 3



d) Velocity Profile for Line 4

2.3 Effect of Pitch Angle

After validating the numerical model , the simulations for the same ansys settings and input parameters of 4.5m/s and 400 rpm were executed and the results were tabulated and graphs were plotted upon.

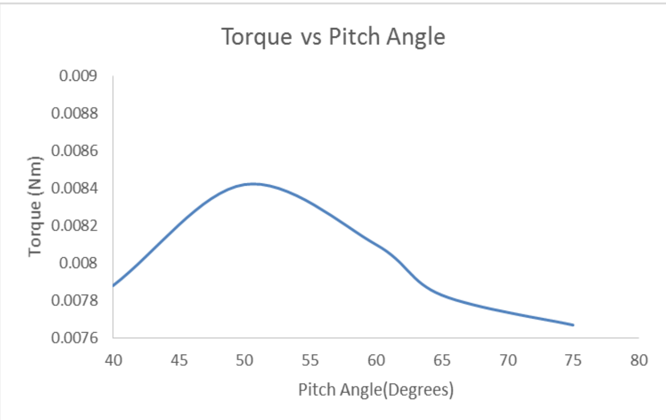


Fig – 4 : Variation of torque with pitch angle of blade

2.4 Effect on torque value with varying inlet velocities

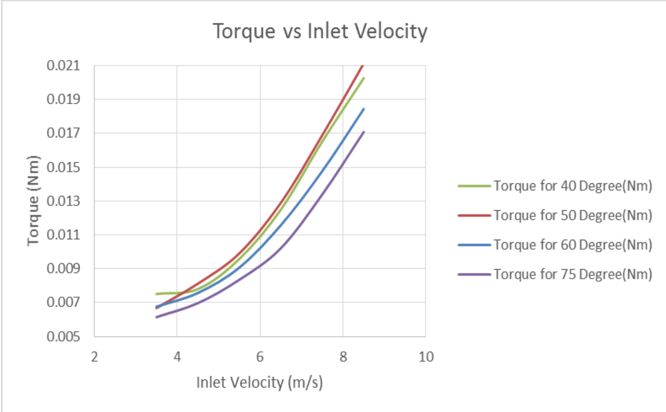


Fig – 5 : Plot between Torque and Inlet Velocity for different pitch angles

The 50° pitch angle model shows higher levels of torque which can be attributed to better momentum transfer from the inlet wind stream to the turbine blade surface. The increasing inlet velocity values causes higher torque values to be produced on all the models and all the turbine blade models show similar behavioural changes in terms of torque value when the inlet velocity values are increased from 3.5-8.5 m/s.

3. CONCLUSIONS

An unconventional category of HAWT inspired from the Archimedes spiral blade structure was taken. A numerical approach to design the Archimedes wind turbine was implemented. A comparison of the theoretical prediction of the wind turbine aerodynamic performance and that of Fluent numerical analysis has good agreement. As observed from the graph, the inflection point can be found at the angle of 50° as the torque value first has an increasing trend line and after the inflection point decreases again

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REFERENCES:

[1] Kyung Chun Kim and Ho Seong Ji, "Experimental and Numerical Study of the Aerodynamic Characteristics of an Archimedes Spiral Wind Turbine Blade," D. Kornack doi:10.3390/en7127893.

[2] Small Wind World Report Summary 2012; World Wind Energy Association: Bonn, Germany, 2012.

[3] Renewables 2011 Global Status Report; Renewable Energy Policy Network for the 21st Century (REN 21): Paris, France, July 2011.