Design, Fabrication and Experimental Analysis of Archimedes Spiral Wind Turbine

B Rakesh[1], Dr S Srinivasa Rao[2], Ch Y V Kiran kumar[3], Anand kumar M[4], D Duryodhana[5]
[2] *Associate Professor, Department of Mechanical Engineering, MVGR College of Engineering (A) Vizianagaram, Andhra Pradesh., India*
[1,3,4,5] *Graduate student, Department of Mechanical Engineering, MVGR College of Engineering (A) Vizianagaram, Andhra Pradesh., India*

Abstract- **The paper deals with the Design, fabrication and experimental analysis of Archimedes spiral wind turbine which gyrates at a low wind speed and is highly adaptive for household electricity necessities. Archimedes wind turbine (AWT) is a new type of Horizontal axis wind turbine comprising three circular blades which are wrapped around each other and then expanded about the shaft. This special design ensures that more air is harvested by the turbine utilizing the tangential, axial and radial forces so that more power is extracted from wind. The design of the model is done in Creo parametric and fabrication is done through 3D printing of the IGES part file using the ABS(Acrylonitrile-Butadiene-Styrene) material.CFD simulations in Ansys Fluent. The ultimate objective of this work is to compare the power obtained from experimental and analytical analysis of Archimedes turbine. The power produced by the turbine at lower and higher wind speeds is good and the power production increases as the wind speed increases, following a linearly increasing trend and in order to prove the results are correct and satisfactory, validation is done with the help of experimental results.**

Index Terms- Archimedean spiral, Betz limit, CFD Fluent, Low wind speeds, Power generated.

I. INTRODUCTION

The prolonged depletion of conventional sources of energy in nature led to the quest of renewable power resources. One among them is the Wind energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities in air streams across the earth's surface, and rotation of the earth. Wind flow patterns are due to the changes in earth's terrain, bodies of water, and vegetative cover(floral). This wind flow when "harvested" by the wind turbines, reaps the wind power to generate electricity. Wind turbines convert the available kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grains or pumping water) like in early Dutch windmill applications or a generator can convert this mechanical power into electricity to power homes, schools and the like. Wind turbines are available in various sizes, and so different power ratings. There are 2 types of wind turbines The Horizontal axis wind turbine(HAWT) and the Vertical axis wind turbine(VAWT). The HAWT functions using the lift principle. The blade operates like an aircraft's wing, generating a lifting force

relative to the blade. Such blades do require a higher degree of accuracy and end finish. The VAWT functions on the drag principle like the boat running on the paddles[1]. The three-bladed horizontal type wind turbines are common in production by the industries for wind farms.

Archimedes wind turbine(AWT) is a new type of HAWT which functions utilising both the lift and drag principles allowing it to extract more power than the existing wind turbines. Moreover it is quite responsive at low wind speeds, bird friendly and produces less noise[2]. In India, an average wind speeds are 3 ms-1 at 20m height; therefore Archimedes wind turbine is perfect for low and medium wind speeds. In 2009, Timmer and Toet used the selective laser sinter method to modify the Archimedes wind turbine model and carried out a fundamental research to explore its potential and find out optimum power output[3]. In 2014, Kyung Chun Kim, Ho Seong Ji investigated the aerodynamic performance of Archimedes wind turbine by using CFD analysis, 2D Particle image velocimetry (PIV) method is used to examine CFD results in the near field of the blade[4]. The Tip speed ratio(TSR) is the ratio between the rotor blade's tip speed and the wind speed. A resistance type rotor(VAWT) is generally made out of flat surfaces with a tip speed ratio smaller than or equal to 1. The tip speed ratio in lift type turbines(HAWT) is larger than 1. The speed of the blade tip is therefore greater than the wind speed. A higher relative tip speed means higher efficiency, but is also related to more noise and a more robust and heavier design[5].From the literature survey it is observed that the traditional AWT has its blades 60º about the rotor axis. In this study, development of surface is done in the 3D model and design is modified by altering the angle to 90º.

Design of Archimedes spiral rotor blade of size 250 mm diameter and 270 mm length has done by CREO 2.0 and the commercially available software ANSYS Fluent is employed to predict the aerodynamic performance such as torque, power, lift & drag force, velocity and pressure distribution, according to wind condition using RANS model with a k-omega Shear Stress Transport (SST), based on Finite element method (FEM).The analytical, experimental and theoretical power output are validated and compared. The minimum wind speed required to initiate the gyration of the rotor is 3m/sec which is a domestic wind speed. The velocity profiles are in a good agreement between experiment and CFD Fluent analysis, the trajectory and magnitude of tip vortices generated by the blade are identified from the pressure and velocity contour results.

II. DESIGN and FABRICATION of ARCHIMEDES SPIRAL WIND TURBINE

A spiral is a curve in the plane or in a space, which runs around a centre in a intruding way. If a spiral is made by two motions about a point that is, a uniform motion in a fixed direction and a motion in a circle with constant speed, both motions start at the same point. Figure 1 shows the geometric representation of the Archimedes spiral wind turbine of dia 250mm and length 270mm.

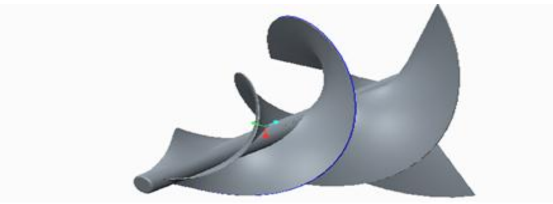


Fig 1 - Archimedes rotor blade

The part file of the turbine rotor with shaft holder is fed to the 3D printing machine and the prototype(Figure2) is made of ABS material(Acrylonitrile Butadiene Styrene) so as to get a hard enough, heat resistant 3D model of 250mm diameter AWT blade. The inner radius of hole for the shaft to fit is 16mm. The fabricated model with final assembly of all attachments like frame, base and generator coupling is shown in Figure 3.

Fig 2 - 3D Printed blade

Fig 3 - Fabricated turbine assembly

III. EXPERIMENTAL ANALYSIS

An experimental setup is made to measure the rotor output speeds at various inlet wind speeds. Experiment is carried out at no load and various loads in natural wind and artificial blower. To find the power output from load testing, torque is measured using an rope brake dynamometer setup where the pulley or break drum is connected to the aluminium shaft of the turbine. Here the pulley is made of light weight material (Acrylic glass) so as to allow minimise the losses due to inertia about the rotor axis.

Fig 4 - Load testing setup

TABLE I.POWER GENERATED AT VARIOUS LOADS

At 50 gms load,

S.No	Wind speed(m/s)	Speed of turbine(rpm)	Experimental Power output(W)
1	4.5	192	0.441
2	6.2	367	0.843
3	7.5	489	1.121
4	8.6	558	1.49

At 100 gms load,

S.No	Wind speed(m/s)	Speed of turbine(rpm)	Experimental Power output(W)
1	4.5	111	0.449
2	6.2	196	0.849
3	7.5	248	1.142
4	8.6	351	1.565

At 150 gms load,

S.No	Wind speed(m/s)	Speed of turbine(rpm)	Experimental Power output(W)
1	4.5	65	0.463
2	6.2	124	0.852
3	7.5	189	1.224
4	8.6	249	1.724

At 200 gms load,

S.No	Wind speed(m/s)	Speed of turbine(rpm)	Experimental Power output(W)
1	11.5	483	4.39
2	15	597	5.426

IV. CFD SIMULATION

Computational fluid dynamics (CFD) is the branch of Fluids that uses numerical approaches and algorithms to solve and validate problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interactions of liquids and gases with surfaces defined by the boundary condition. CFD helps scientist and engineers to achieve numerical experiments, i.e. Computer simulations in a virtual laboratory. CFD is quicker and of course inexpensive. A considerable reduction in time and expenses for solving the problems as compared to traditional approaches. Various steps undergone to perform the CFD simulation by importing the IGES part file and creating a cylindrical enclosure like in Figure 5.

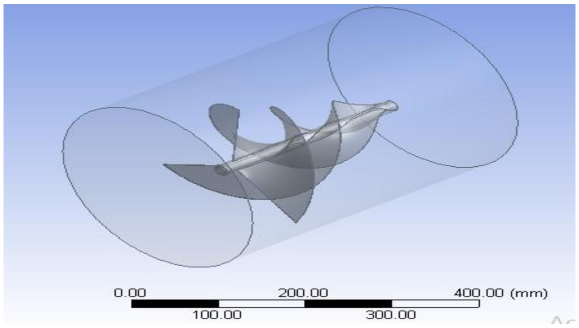


Fig 5 - Turbine blade with enclosure

An Amorphous mesh is generated around the blade in the cylindrical domain as shown in the Figure 6 with inlet and outlet conditions. Number of nodes on tunnel and rotor (AWT) after meshing are 81746 and 429669 are total elements in hex-dominant method.

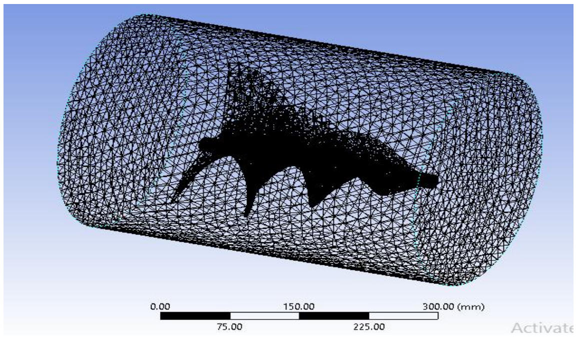
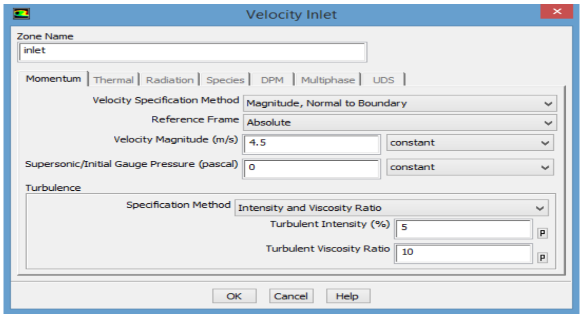


Fig 6 - Medium meshed model

CFD FLUENT consists of various turbulence models in which Shear Stress Transport (SST) k-ω turbulence model has been used to forecast the separation of flow which is two equation-based model. SST k-ω turbulence model uses the benefit of both k-ε and k-ω turbulence model where k is turbulence kinetic energy, ε is the rate of dissipation of the turbulent kinetic energy and ω is the specific rate of dissipation.

The boundary conditions given are input wind speeds : 4.5m/sec, 6.2m/sec, 7.5m/sec, 8.6m/sec like in Figure 7 and their respective rotor angular velocities obtained from experiment at different loads.


Velocity Inlet

Zone Name: inlet

Velocity Specification Method: Magnitude, Normal to Boundary

Reference Frame: Absolute

Velocity Magnitude (m/s): 4.5 constant

Supersonic/Initial Gauge Pressure (pascal): 0 constant

Turbulence

Specification Method: Intensity and Viscosity Ratio

Turbulent Intensity (%): 5

Turbulent Viscosity Ratio: 10

Fig 7 - Inlet wind speed

V. RESULTS

The results from CFD simulation are obtained in terms of streamlines, pressure and velocity contours, functions calculated torque and therefore power generated.

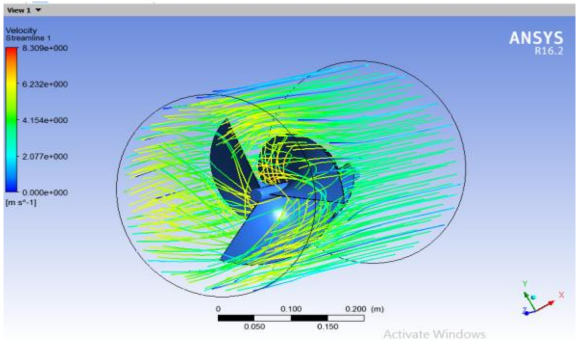


Fig 8 - Streamlines

The velocity is distributed as such in Figure 9, it is maximum at the centre of mass of the turbine along the shaft and minimum at the exit of blade if constant wind speed(yellow line) at wall is ignored.

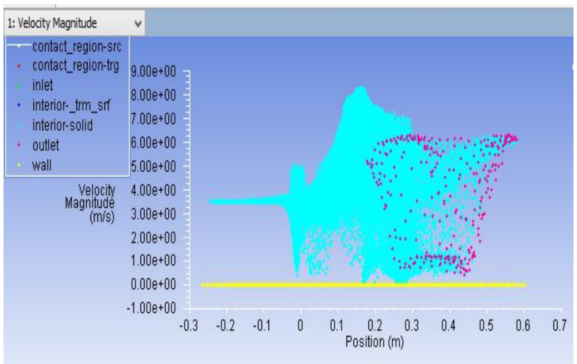


Fig 9 - Velocity distribution

The maximum pressure has found around the blade and lowest was at the back edge. The pressure distribution of the AWT has shown in Figure 10. a pressure difference is more inside among the pressurized and vacuum side thus leads to generate more torque and thus power. When the wind speed rises the pressure difference increases, means more energy can be extracted. Exit pressure is negative at the finish of the blade is found from the function calculator.

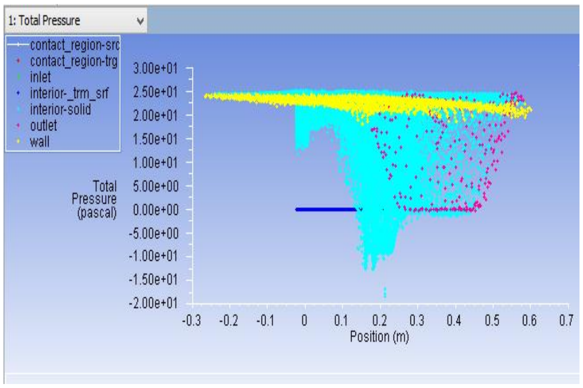
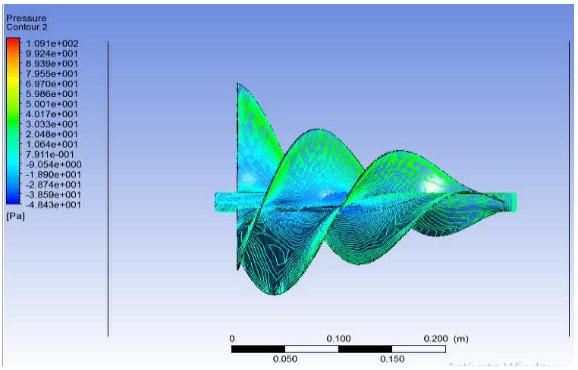
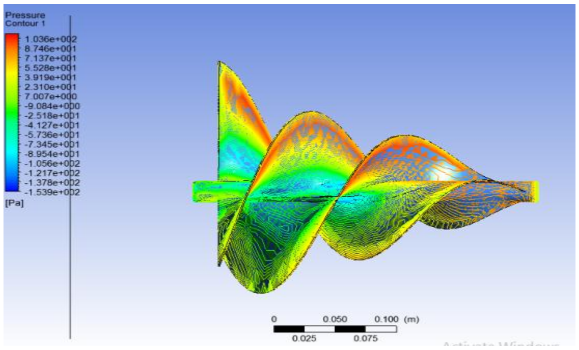


Fig 10 - Pressure distribution

The pressure contours at different inlet wind speeds are,



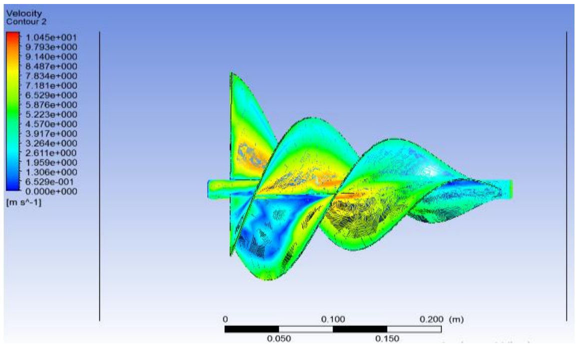
4.5 m/sec



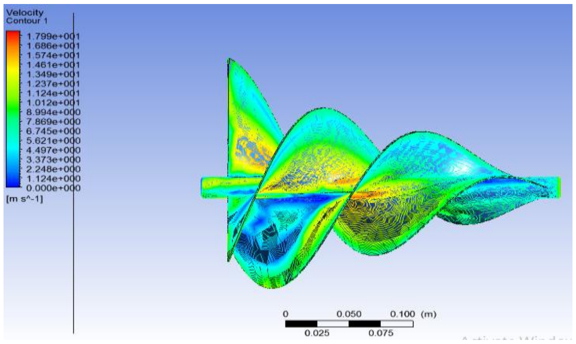
7.5 m/sec

As the red colour in the contour intensifies the value of parameter increases, i.e. pressure. So it is clear that as wind speed increases the pressure at the blade tip increases.

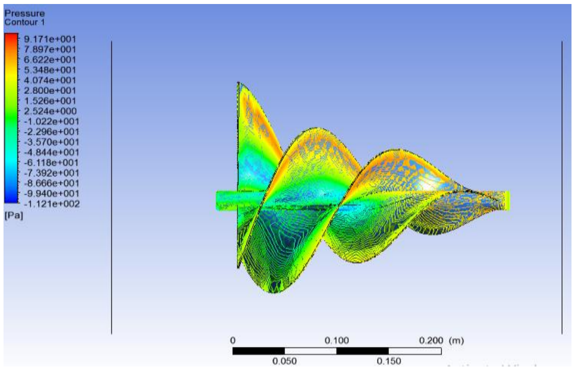
The velocity contours at different inlet wind speeds are,



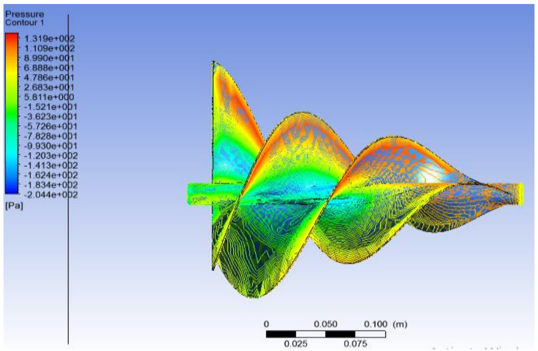
4.5m/sec



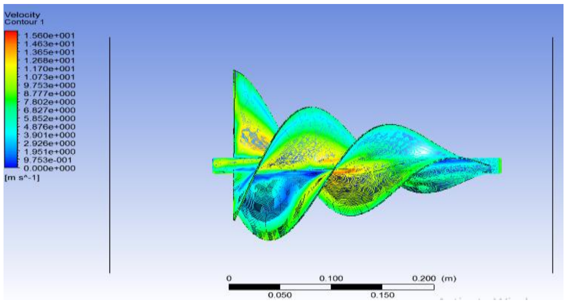
7.5m/sec



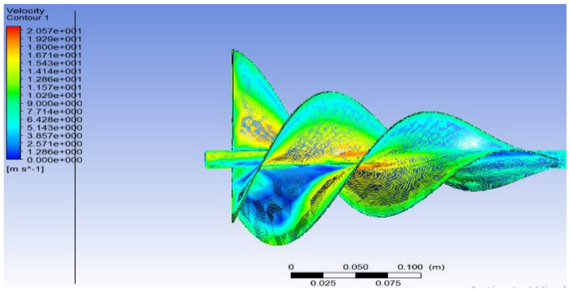
6.2 m/sec



8.6m/sec



6.2m/sec



8.6m/sec

The velocity at the centre of mass of the rotor blade is generally maximum for a fixed wind speed. Now as the wind speed increases the velocity or turbulence of air at the centre of mass is also rising indicated by red colour

The variation of power generated at different wind speeds like 4.5m/sec, 6.2m/sec, 7.5m/sec, 8.6m/sec and corresponding rotor velocities are plotted as follows figures 11,12,13,14.

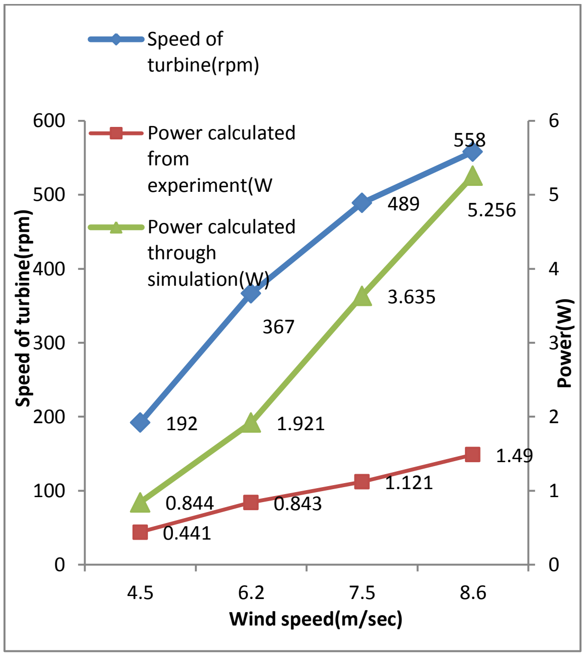


Fig 11 - Variation of Power(W) And Rotor Speed(rpm) w.r.t Wind Speeds(m/s) at 50gm Load

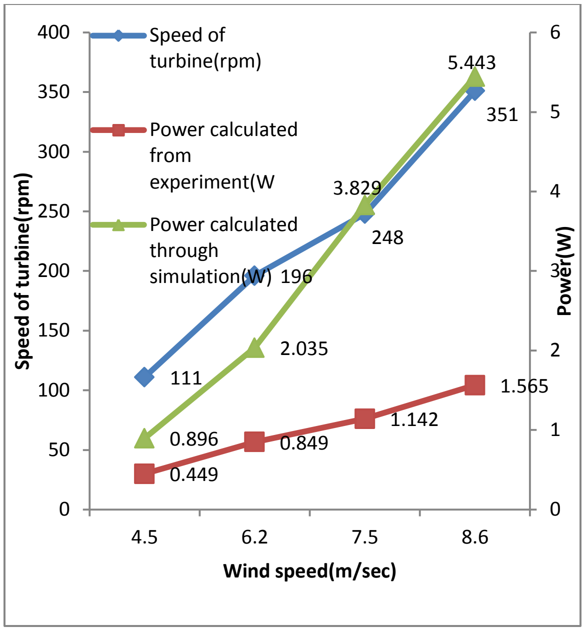


Fig 11 - Variation of Power(W) and Rotor Speed(Rpm) w.r.t Wind Speeds(m/s) at 100gm Load

So as the load increases the power needed to overcome the restoring torque increases with increasing wind speeds. Also there exists a cut-off load for every wind speed at which the turbine loses its threshold and stops responding to further increase in load.

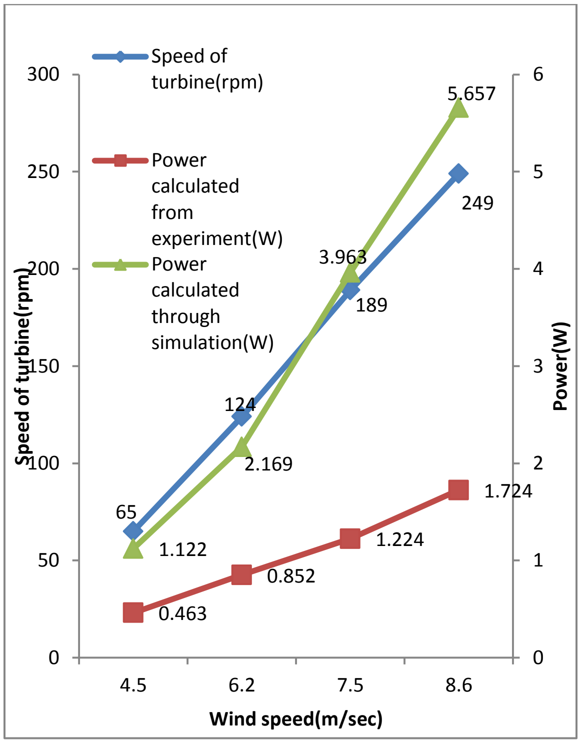


Fig 13 - Variation of Power(W) and Rotor Speed(rpm) w.r.t Wind Speeds(m/s) at 150gm Load

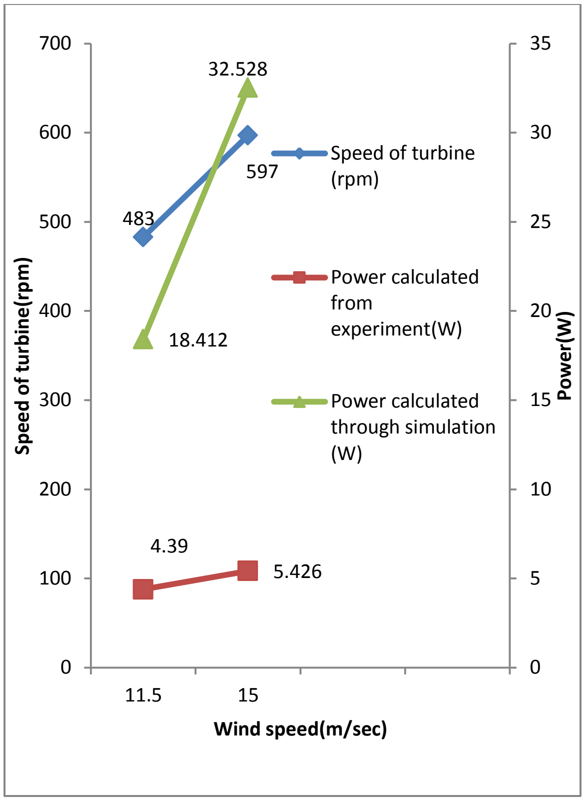


Fig 14 - Variation of Power(W) and Rotor Speed(rpm) w.r.t Wind Speeds(m/s) at 200gm Load

At lower wind speeds, as the load is 200 gms, the rotor is not responsive to overcome the opposing torque due to load. Again from 11.5 m/sec the power generated is comparable with the simulated results. Both the experimental and simulated results are following an increasing trend as the wind speed increases.

VI.CONCLUSION

The aerodynamic features of an Archimedes wind turbine are purely based on wind speed and design parameters. To study the torque features of the Archimedes wind turbine, CFD has been on the Archimedes wind turbine at different wind and rotor speeds summarized as

- Developing the blade surface by altering the blade angle from 60° to 90° so as to allow free flow of air around the vortex surface which fairly increases the power at a lower wind speed and thus suggests it is more suitable for low and moderate wind speeds.
- It shows that power is the outcome of wind speed and design parameters of wind turbine blade.

- There is no need for electric yawing equipment as the turbine uses tangential, radial and axial forces which reduces the cost and maintenance.
- According to the CFD results, Archimedes wind turbine looks getting more promising power than the other HAWT's if proper power extracting devices are functioned i.e low torque and low speed dynamo because the rotor blade is capable of rotating at higher speed but at lower torque which is solely consumed in opposing inertia.
- The simulated results of velocity distribution and pressure contours describe that the power produced is increasing as the wind speed increases. For the 250mm AWT , the minimum wind speed required for power generation is 2.5m/sec with no load and when load test is done a minimum speed of 4.5m/sec is required from 50gm onwards.

VII.FUTURE SCOPE

Any future work on this Archimedes spiral wind turbine can be appraised if on utilizing and governing the power output to an optimum level by implanting better power churning equipments. Also based on the area of the turbine blade, the power output differs, so optimum area that is practically compatible with the design of other machine elements like frame and yawing system is to be found and made as standard for further research and comparisons.

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