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Efficiency Analysis of Archimedes Wind Turbine Using CFD Technique

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Abstract— Wind energy is a renewable and clean form of energy with enormous potential for power production in Pakistan. The country is facing energy crisis as the demand of electricity is increasing at higher rate as compared with the supply. However, by using renewable resources in addition with fossil fuels the increasing electricity demand can be met. A total of 306 MW of wind-based generation capacity is installed in Jhimpir wind corridor in Pakistan. However, on the small scale or standalone wind system can have better application. For that purpose, CFD technique was used in ANSYS 16.0 to analyse the efficiency of a wind turbine on small scale. Four different models of same cross-sectional areas were considered at a constant wind velocity of 5 m/sec for carrying out simulation. The model with high efficiency of 30.3% was selected with a geometry of 60 cm diameter, 40 cm pitch of the blade and 70 degrees of opening angle for maximum power coefficient at tip speed ratio of 2.5. The results show that the parameters of the developed model have highest aerodynamic efficiency of 30.3% as compared with a 3-blade small scale horizontal axis wind turbine, which having efficiency of 21% and small scale vertical wind turbine having efficiency of 45% at wind speed of 9 m/s. The maximum power output from simulation was 6.55 W at wind speed of 5 m/s and turbine rotational speed of 398 RPM. This model was fabricated and tested for power, coefficient of power and efficiency and it was found that simulated and fabricated Archimedes wind turbine performance parameters were deviated by 3% only.

Index Terms— ANSYS (Analysis System), CFD (Computational Fluid Dynamics), RPM (Revolutions Per Minute), Renewable energy, Wind turbine.

1 Introduction

In order to fix the energy supply issues, tackling the climate change, reductions of Greenhouse Gas (GHG) emissions, biodiversity protection and development of renewable technologies, energy conservation, and efficiency improvements are becoming increasingly important. Among the renewable resources, wind energy is a fairly established technology with huge possibility for commercialization and bulk production. Different types of wind turbine are available like lift-based Horizontal and Vertical Axis Wind Turbines and drag-based Savonius. The major application of wind power is electricity generation from large grid-connected wind farms. [1] With the expansion of the power grid and the reduction of electricity scarce areas, small-scale wind turbines are now being applied in several countries and in many fields, such as city road lighting, mobile communication base stations, offshore aquaculture, and sea water desalination. [2] The Archimedes wind turbine targets the households of urban areas as the wind energy available could be harnessed. The proposed turbine could be installed at a place where the wind speed is less than 3 m/s. The turbine easily fits on the roof just as the solar panels. So, the turbine can be used in cities in order to fulfil the daily energy needs. The turbine can also be used for following applications such as in between the large power generating wind turbines which require minimum speed of more than 3m/s, street lighting, as hybrid source with solar panels for constant output as well as used as backup sources for different purposes.

2 Design And Fabrication

This methodology is created by using Solidworks software for the designing of Archimedes Wind Turbine. The design takes after the Archimedes screw pump, a helix-patterned pipe (used in ancient Greece to pump water) with blade that fans out from the front to back in the shape of a cone-like spiral which allows it to swivel and collect gusts of wind entering at angle as wide as 60-70 degrees from the axis. The fabrication of Turbine blades has been carried out Throatless shear process which is used to make complex straight and curved cut in sheet metal. After cutting the blades hammering process has been used for the desired Archimedes Spiral Curved shaped blade. In this way, three blades were generated. After generating the blades, blades were permanently assembled to the shaft of turbine.

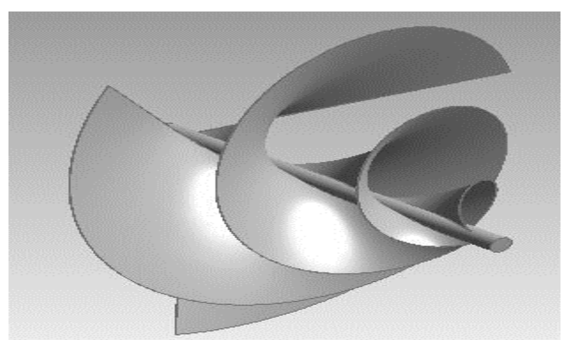

Fig.1. Designed Archimedes Wind Turbine

Fig.2. Fabricated Archimedes Wind Turbine

3 EXPERIMENTAL AND COMPUTATIONAL METHOD

A. Experimental Method

Experimental Analysis of fabricated model was carried out to calculate the power of turbine shaft, spring balance, a flat belt and pulley was used. Various readings were taken at different loads.
The power was calculated by following formula

$$P = T \times 2\pi N/60$$

Where T is Torque
$T = F \times R_p$
Where F is load in newton that was applied on pulley attached to turbine shaft and Rp is radius of pulley.

B. Computational Method

Computational fluid dynamics is the branch of engineering which is uses analysis of system involving fluid flow, heat and mass transfer, chemical reaction and other physical phenomena [3]. The mesh technique has been used for CFD model. The number of elements and number of nodes are 2940562 and 1026543 respectively.
For the relevant comparison of different geometry. CFX setup parameters are kept same for all trails. The models selected are as follows:

Viscous model: SST K-w with all parameters kept by default.

Material: Simple Air (Incompressible)

Viscosity: Constant

Ambient Pressure and Temperature: Standard atmosphere (101325 Pa and 300K)

Number of Iteration to be run: 2000.

TABLE.1
EXPERIMENTAL DATA OF FABRICATED MODEL AT V_O = 5M/S

Experiments	Load(N)	RPM	P(Watt)	C_P	η
1	2.778	400	3.14	0.1351	13.51
2	4.615	286	3.732	0.1624	16.24
3	9.219	200	5.213	0.211	21.1
4	12.603	158	5.630	0.2401	24.01
5	20.778	100	5.874	0.2614	26.14
6	25.642	85	6.235	0.2836	28.36

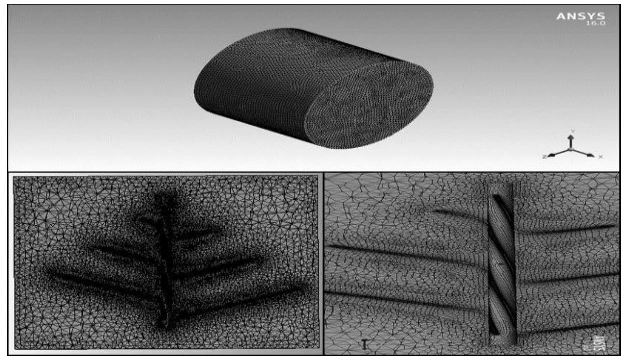

Fig.3. Meshed Model

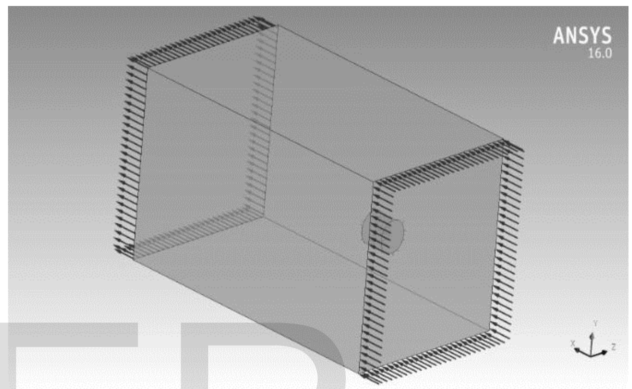

Fig.4. Solver Setup

TABLE.2 BOUNDARY CONDITIONS

S.No.	Boundary type	Operating Condition
1	Velocity Inlet	5 m/s
2	Wind Direction	Parallel to the axis of rotation
3	Interior Domain	Atmospheric Pressure
4	Outlet Condition	Atmospheric Pressure

4 RESULTS AND DISCUSSION

CFD Results for the model (at Blade angle 70º)

Velocity Contours was obtained at the datum plane (x-y plane) which was generated at the middle of the interior domain when looking normal to the screen. (That is z=0). In figure 5 it can be notified that velocity is decreasing when the passing the blade. This reveals that kinetic energy of wind is being converted into mechanical energy of turbine. Also the wake region behind the turbine can be observed.

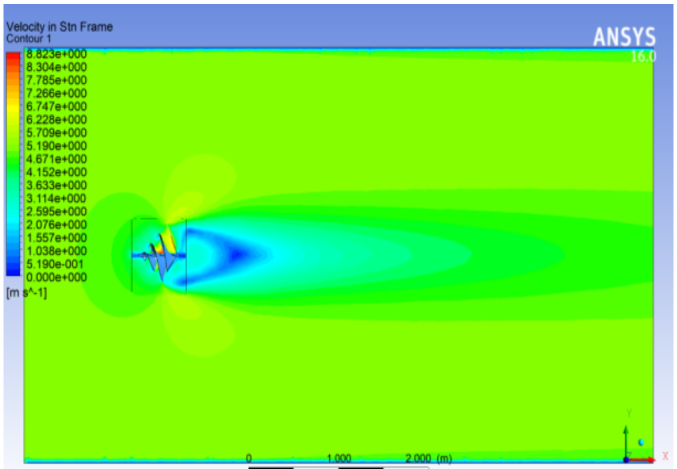

Fig. 5. Velocity Contours

Pressure Contours was obtained at the datum plane (x-y plane) which was generated at the middle of the interior domain when looking normal to the screen. (That is z=0). In figure 6 it can be seen that the pressure in front side of blade is high and at the rare side, it is low. This difference in pressure generates force on blades and due to this action of pressure difference, the turbine rotates. Forces vector are illustrated in Figure.7 that shows the forces in y-direction (perpendicular to axis of rotation) and figure.8. Show the forces in z-direction (perpendicular to axis of rotation). This combination of forces generates a moment, which is cause of rotation of turbine. This combination of forces, acting tangentially to the surfaces of blades, is represented in figure.9.

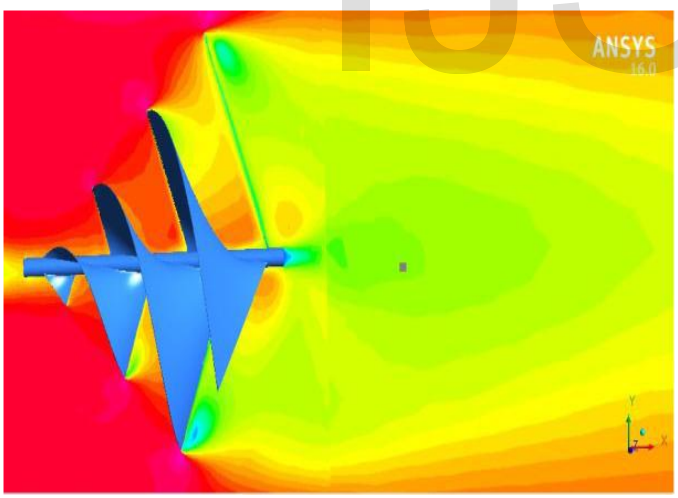

Fig. 6. Pressure Contours

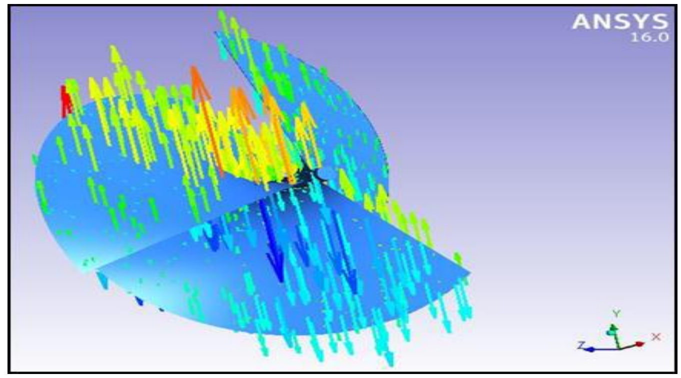

Fig.7. Force vectors in y-axis

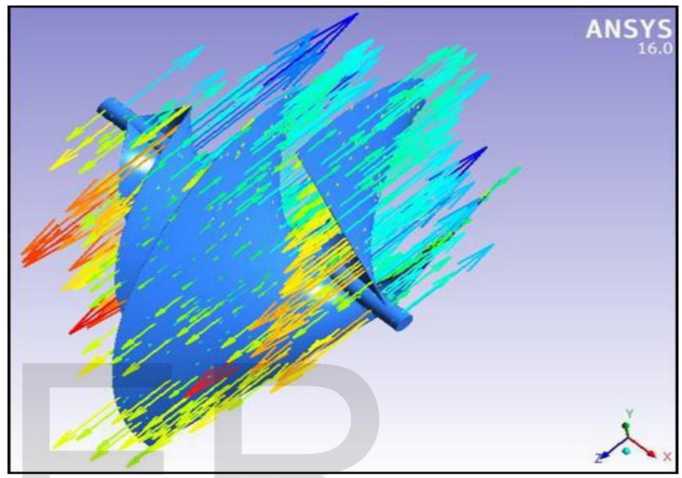

Fig.8. Force vectors in z-axis

Figure 9 shows the force in vector, it can easily be recognized that how the force is acting on the surfaces of blades of Archimedes wind turbine. This force is the cause of rotation of turbine. Magnitude of force computed by the software was found to be 2.75N and Inlet Velocity, V0 = 5m/s.

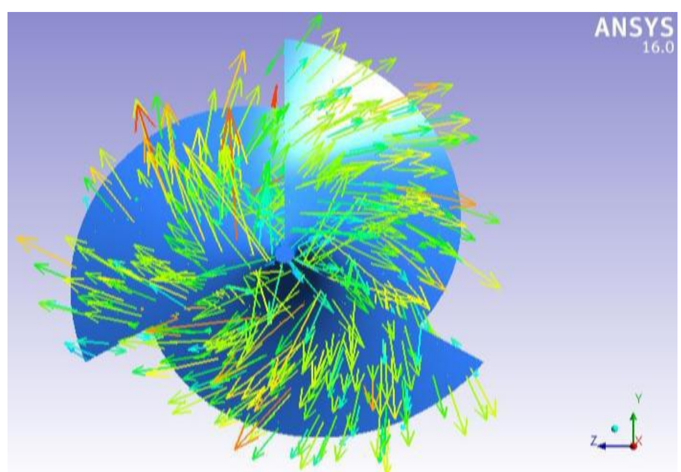

Fig. 9. Combination of forces

TABLE.3 SIMULATION RESULTS OF MODEL

No. of Simulation	TSR	ω (radian/sec)	N (RPM)	P (Watt)	CP	Efficiency (%)
1	0.75	12.5	120	3.562	0.1646	16.46
2	1	16.6667	160	4.23	0.1955	19.55
3	1.5	25	238	5.55	0.2564	25.64
4	2	33.333	319	6.321	0.2921	29.21
5	2.25	37.5	359	6.434	0.2973	29.73
6	2.5	41.6667	398	6.55	0.3030	30.30

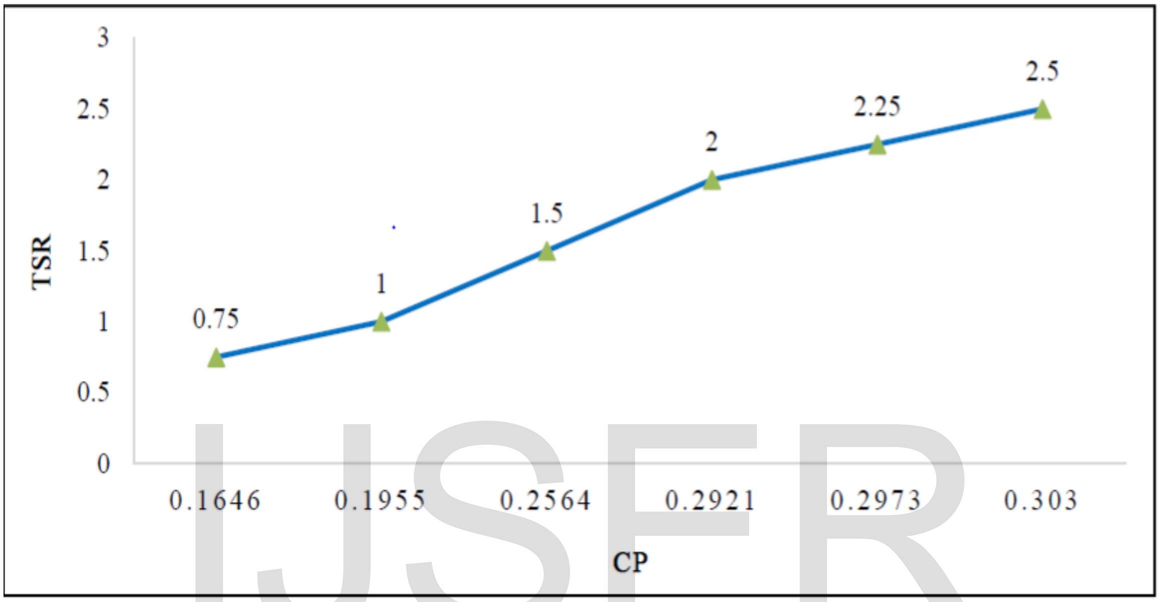

Fig.10. TSR and Cp relationship graph

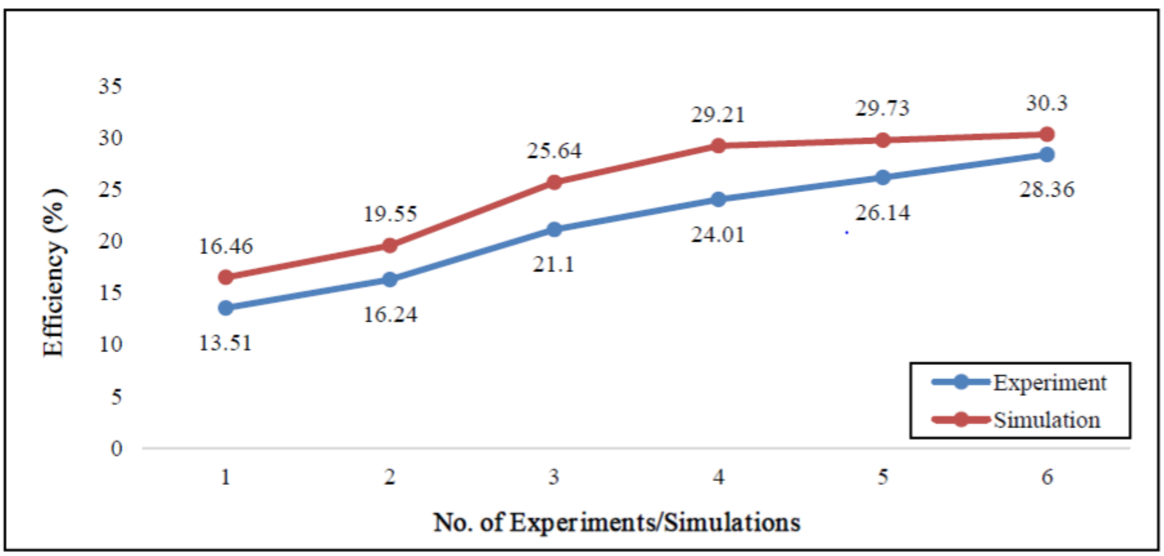

Fig.11. Comparison between Experimental and Simulation Results

From Figure 11 it is analyzed that there is very little difference in experimental and CFD results which losses is occurring at bearing and some human errors during fabrications. It can be concluded that the experimental results were validating the techniques employed for designing the Archimedes Wind Turbine.

5 Comparative study between existing small-scale turbines

1. A small-scale Horizontal Axis Turbine with an airfoil blade design (Rotor Diameter = 40 cm) has the overall efficiency of 21% at wind speed of 4m/s, whereas Archimedes Wind Turbine gives 31.3% efficiency [4].
2. Another small size HAWT airfoil shaped blades generates overall efficiency of 30% at very high wind speed that is at 14m/s but Archimedes Wind Turbine operates at very low speed with great efficiency [5].
3. Vertical Axis Wind Turbine (Darrius) has overall efficiency of 45% at a rated wind speed of 9 m/s. In contrast, Archimedes turbines provide 30.3% efficiency at 5m/s [6].

6 Conclusion

Design optimization of Archimedes Wind Turbine based on blade opening angle was done by using ANSYS CFX software on four different models by performing various simulations. The best model which gave the maximum power was selected for fabrication and then tested to validate the simulation results. Through experiment, the higher output power as a function of rotational velocity than design specification was investigated successfully. Aerodynamic conversion performance through Archimedes wind turbine model employed in this study from wind energy seems to have very higher efficiency than other small wind turbine. The comparison of results between ANSYS CFX simulation results and experimental results validates the design procedure.

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