(EJAST) European Journal of Applied Science and Technology-Novus
e-ISSN: 2785-096X
Journal homepage: https://ejast.novuspublishers.org/ Paper id: 01000113EJAST

Research article

Design and CFD Analysis of Outer Aerodynamics of 10kW Horizontal-Axis Wind Turbine (HAWT) Blade

Muhammad Ahmad*, Faisal Maqsood, Haseeb Nazir, Najam ul Hassan

Department of Mechanical Engineering, University of Engineering & Technology, Lahore, Punjab 54890, Pakistan

ARTICLE INFO

Received: 02.03.2022
Accepted: 21.04.2022
Final Version: 25.05.2022

*Corresponding Author:
Email:
muhammadahmad.pak17@gmail.com

ABSTRACT

In recent years, wind power has been widely recognized and used as one of the most promising renewable energy sources. However, there exists sufficient difference in the available wind perspective and the overall power production. It is essential to eliminate this energy problem in Pakistan by optimizing the design of renewable energy resources. Pakistan has very good wind potential, especially in the provinces of Sindh and Baluchistan. In the current research study, a 10,000-watt horizontal axis wind turbine (HAWT) is designed for the Taftan, Baluchistan region to meet the energy requirements of Pakistan. The Blade Element Momentum (BEM) method is utilized to design the HAWT blade profile while computational fluid dynamics (CFD) analysis is conducted to evaluate the designed profile.

Keywords: Aerodynamics, Wind turbine, TSR, Warlock, CFD analysis

Introduction

It is very difficult for developing countries including Pakistan to fulfil the energy needs of the whole population. To extract energy from renewable resources has become the need of the hour [1]. Energy consumption, energy conversion, and their problem-solving method is getting more and more attention for rotating machinery. Heavy-duty turbines are always being subjected to new challenges to be efficient with the increasing energy demands [2, 3]. There are different renewable resources such as solar, wind, biomass and hydropower potential [4]. The government of Pakistan is struggling hard to overcome the energy crisis by initiating mega power projects to achieve sustainable development goals [5, 6]. The method to extract the energy from wind is getting mature and reliable all over the world [7-9]. The explanation of “small wind” is essential. In the wind energy industry, the word “small” remained vague and its meaning had been changing with time [10-12]. Several parameters are required to obtain the optimal design of a wind turbine. These parameters include the number of blades, the material of blades, length of the blade, rotor diameter, tip speed ratio, the wind cut in and cut out speed, rated power, tower height, etc.

Hence the current study presents the design of a 10KW horizontal axis wind turbine (HAWT) to fulfil the energy needs at the microscopic level in Pakistan. Warlock wind turbine calculator is used to examine different designed parameters. To justify the proposed design, computational fluid dynamics (CFD) analysis is also conducted in the current study. The proposed work provides a pollution-free, decentralized and reliable energy framework.

Design Parameters

Analyzing the wind speed in different districts of Pakistan, the Taftan, Baluchistan region is selected in this study for the design of 10KW HAWT. The gearing method is the planetary gearbox.

Table 1. Design parameters

Generator	**Type**	**Permanent magnet 3-phase AC electrical**
	Max Power	14 kW
	Rated Power	10 kW
Rotor	Configuration	Horizontal Axis
	No. of Blades	3
	Material of Blades	Glass Fiber or reinforced fiber
	Length of Blade	4.61 m
	Rotor Diameter	3.2 m
	Swept Area	66.76 m^2
	Rotor Speed	126.8 rpm
	Tip Speed Ratio	7.2
Wind	Cut in speed	2 m/s
	Rated speed	8.5 m/s
	Cut out speed	30 m/s
Wight	Rotor	1,000 kg
Tower	Hight	50 m
	Material	Stainless steel
	Wind	Upwind

By using Warlock design parameters, the final shape of the wind turbine with tower height is drawn on SOLIDWORKS 2020 by using the loft command.

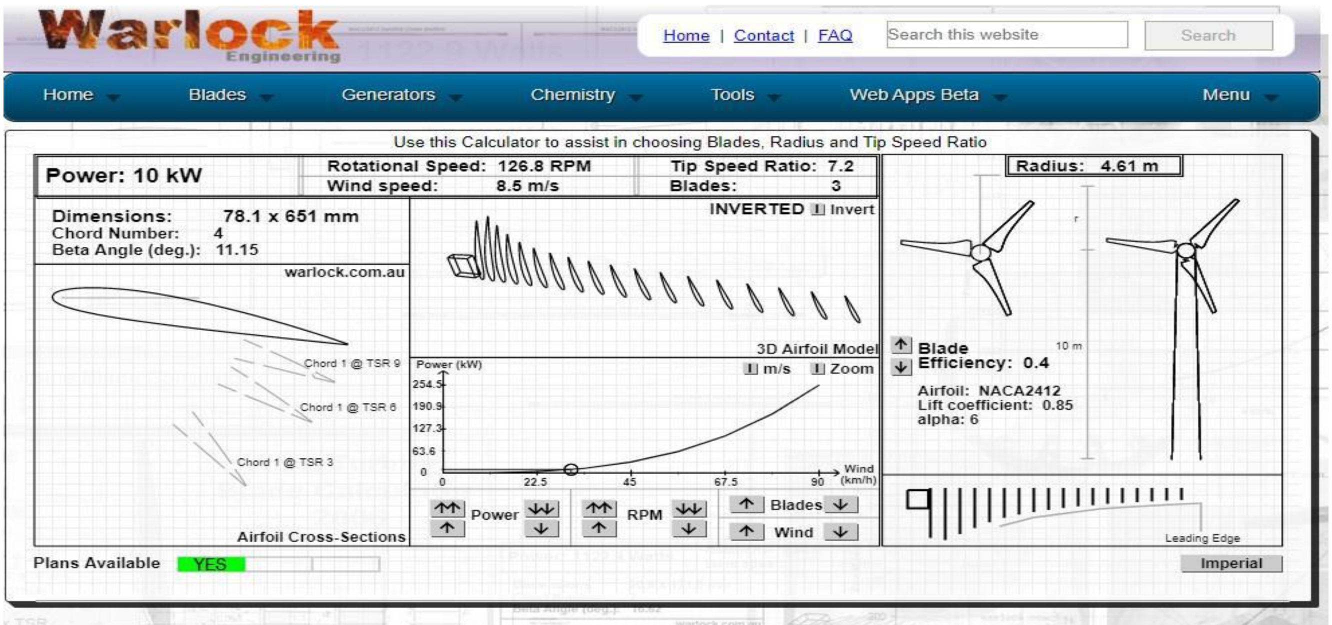

Fig.1 Warlock wind turbine blade calculator

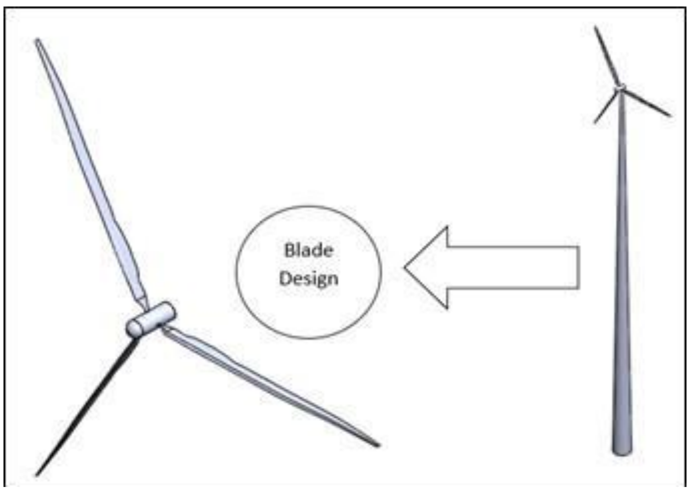

Fig.2 Wind turbine design with tower height

The power of turbine is calculated by using following formula;

P actual = ½ ρ v3 A * Cp
P actual = 10045.57 W
Density of Air = ρ =1.225 kg/m3,
Wind speed = v = 8.5 m/s
Swept area = A = 66.76 m2
Power coefficient=Cp = 0.398
Rotational speed= w=12.27 rad/s or 126.8rpm

The tip speed ratio is the unrelated speed at the tip of the cutting edge against the real speed of the wind, while the power coefficient is characterized as the ratio of the examination between genuine powers produced by the rotor edge with the power following up on the liquid. The following relation is used to calculate power coefficients at different TSR on the different number of blades using different pitch angles.

$$C_p = \frac{1}{2}(\beta - 0.0220\theta^2 - 5.6)e^{-0.17\beta}$$

Where,

$\beta = TSR\ at\ different\ number\ of\ blades$

$\theta = pitch\ angles$

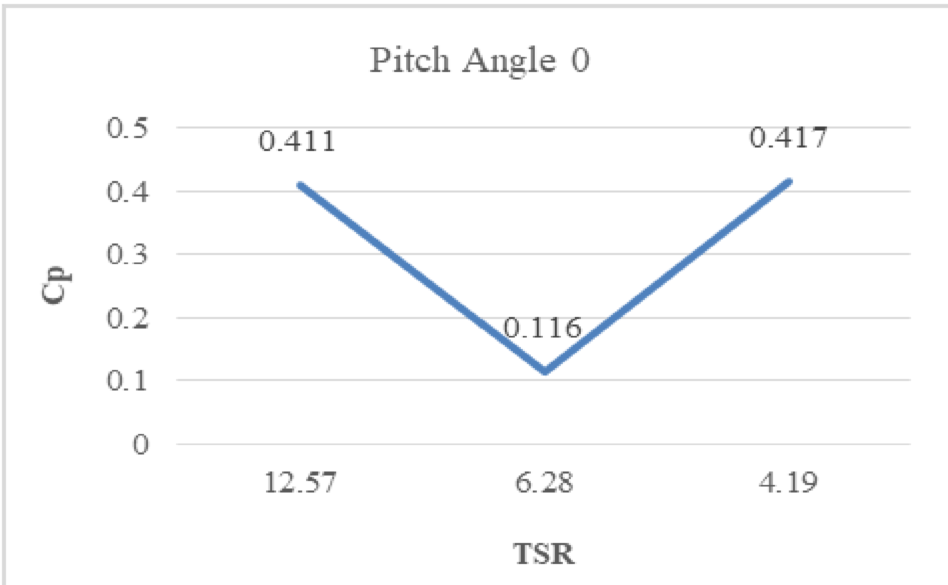

Fig.3 Relation between TSR and C_p for $\theta = 0°$, n= 1,2 & 3

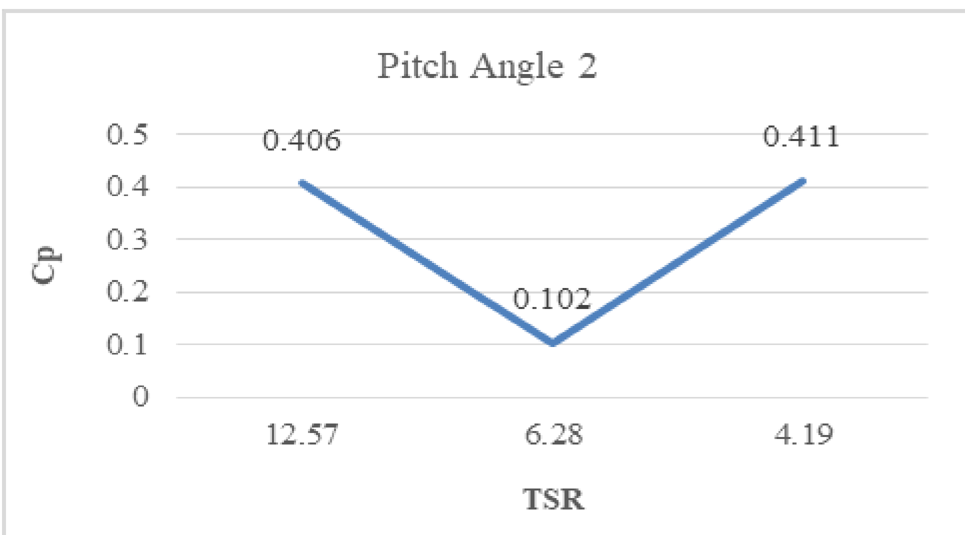

Fig.4 Relation between TSR and C_p for $\theta = 2°$, n= 1,2 & 3

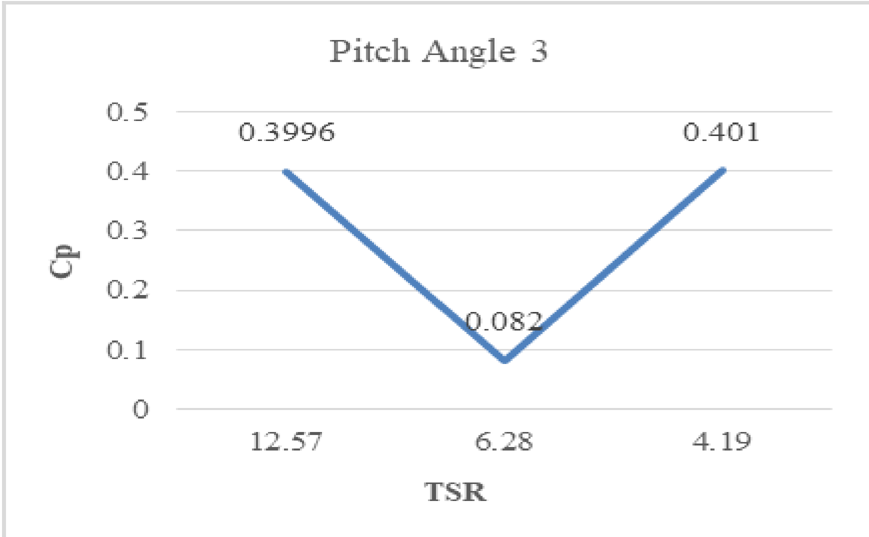

Fig.5 Relation between TSR and C_p for $\theta = 3°$, n= 1,2 & 3

Simulation Analysis

To justify the proposed design, computational fluid dynamics (CFD) analysis is also conducted in the current study. Meshing is performed on ANSYS 19.2, with element size 845.4mm, while the number of elements and nodes are 1055282 and 185556, respectively. The wind turbine design is accomplished by using given conditions and the K-epsilon turbulence model.

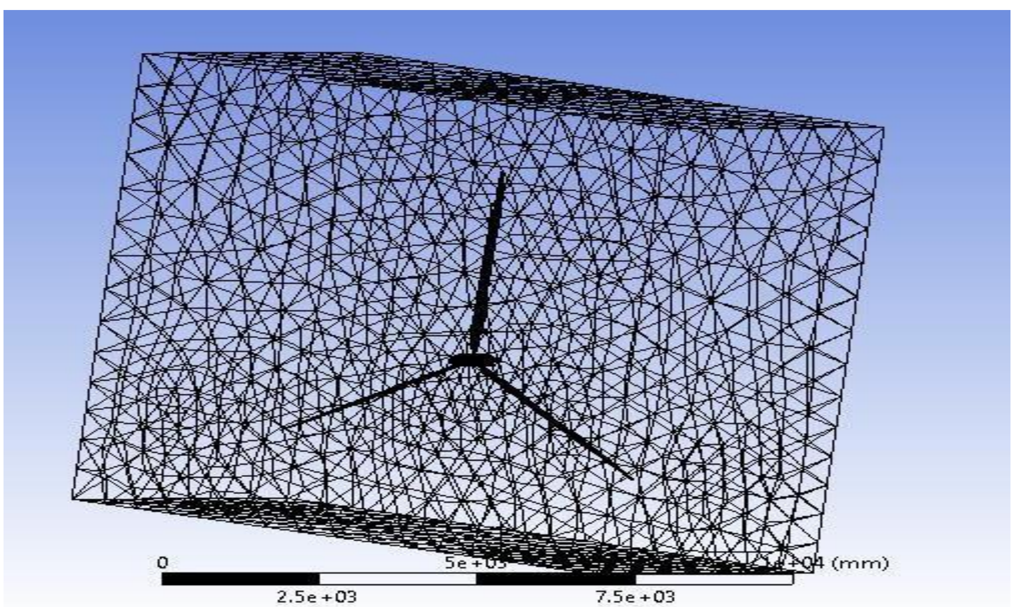

Fig.6 Dissection part of meshing

The lift coefficient (Cl) of the wind blade is calculated 0.26 from Ansys, while the value of drag coefficient (Cd) for airfoil is 0.04. Simulation results of lift and drag coefficients and forces are shown in the following Figures;

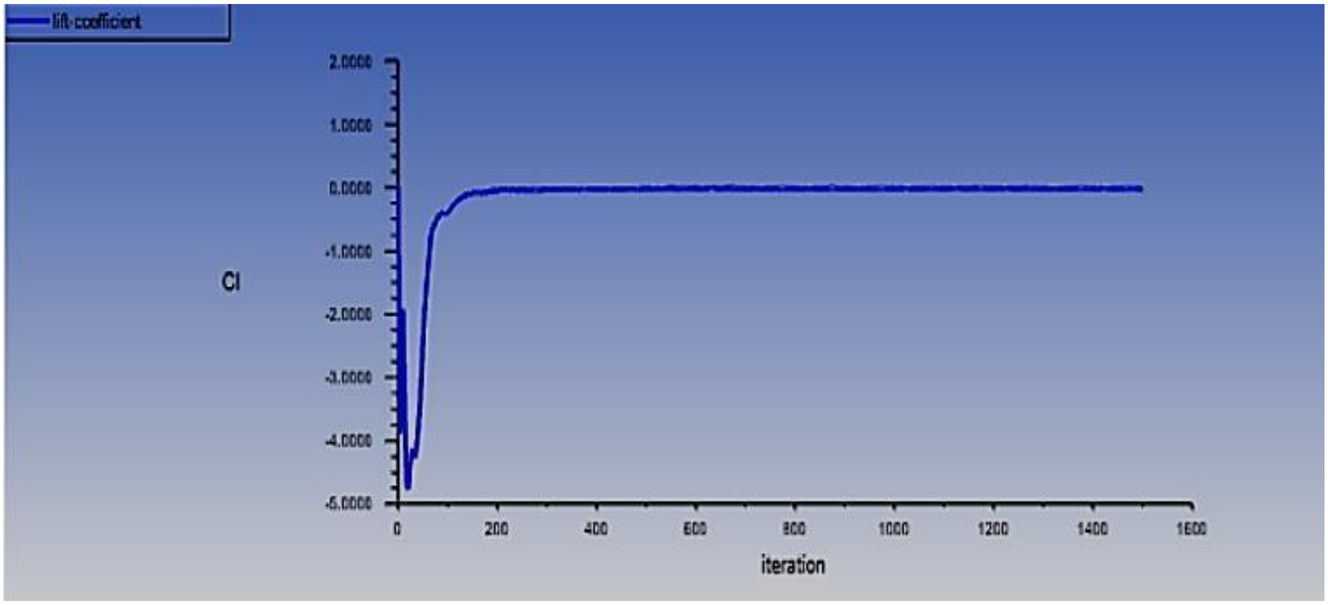

Fig. 7 Lift Coefficient

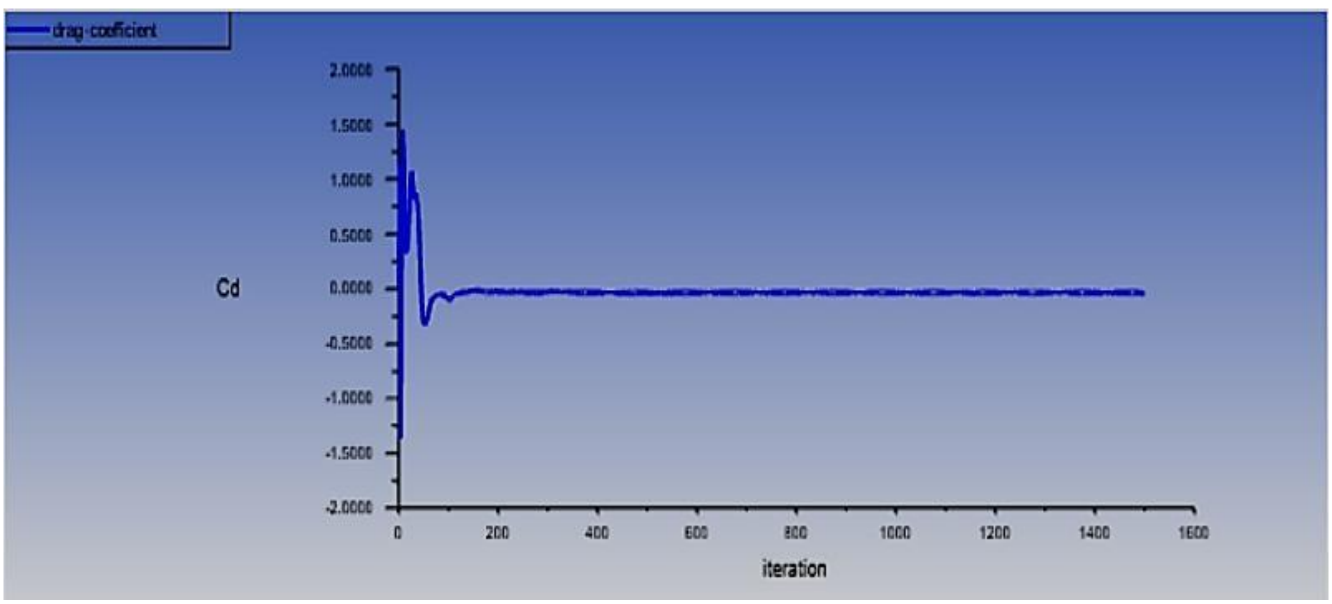

Fig. 8 Drag Coefficient

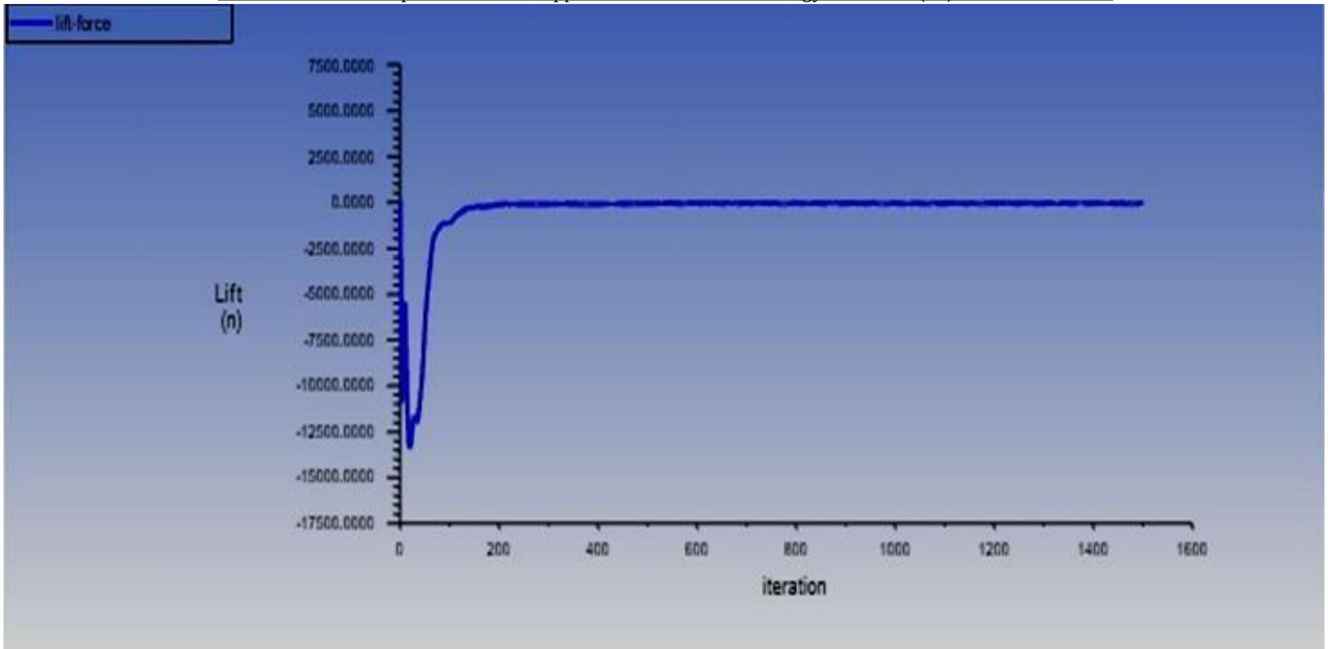

Fig. 9 Lift Force

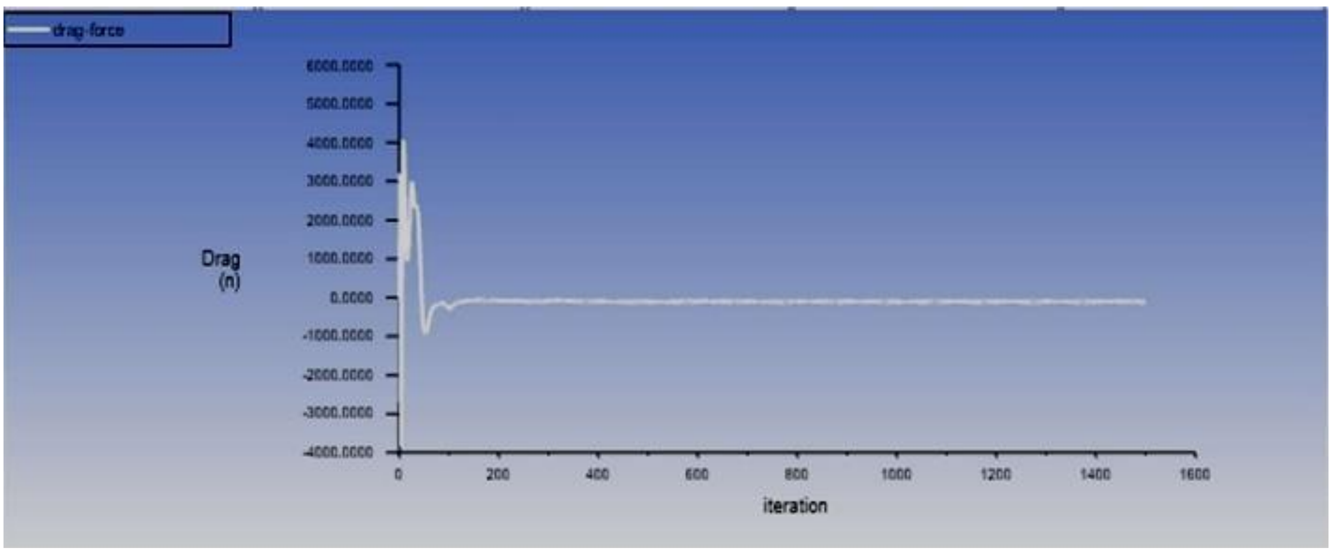

Fig. 10 Drag Force

The wind turns the propeller-like bleeding edges of a turbine around a rotor, which turns a generator, which makes power. So,

P = T*w

As torque on a wind turbine is calculated (774.24 Nm) from Ansys, so power will be

P = 774.24*12.27

P = 9499.92W

Flow distributions are analyzed using the whole model as shown in Fig.11, It can be seen that the blade generate motion due to the high lift coefficient.

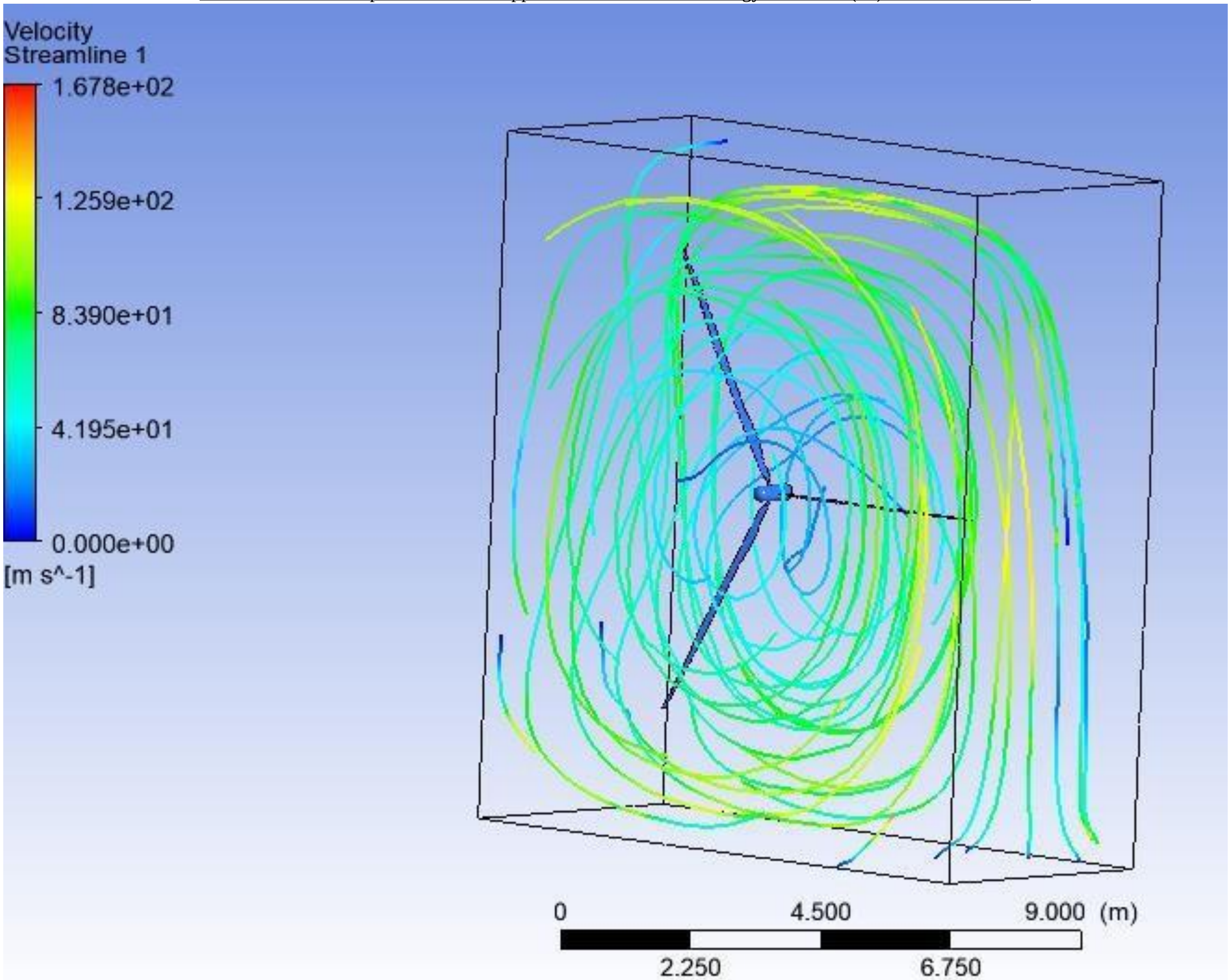

Fig.11 Wind distribution on the whole turbine

The pressure distribution is being taken from the front view and it shows the cut section at the middle of the wind turbine. It represents that the tip of the wind blade shows a decrease in pressure. An airfoil is a 2-dimensional wing segment that addresses basic wing execution qualities. The pressing factor circulation and lift coefficient are significant boundaries that portray the conduct of airfoils. The pressing factor circulation is straightforwardly identified with the lift created via airfoils.

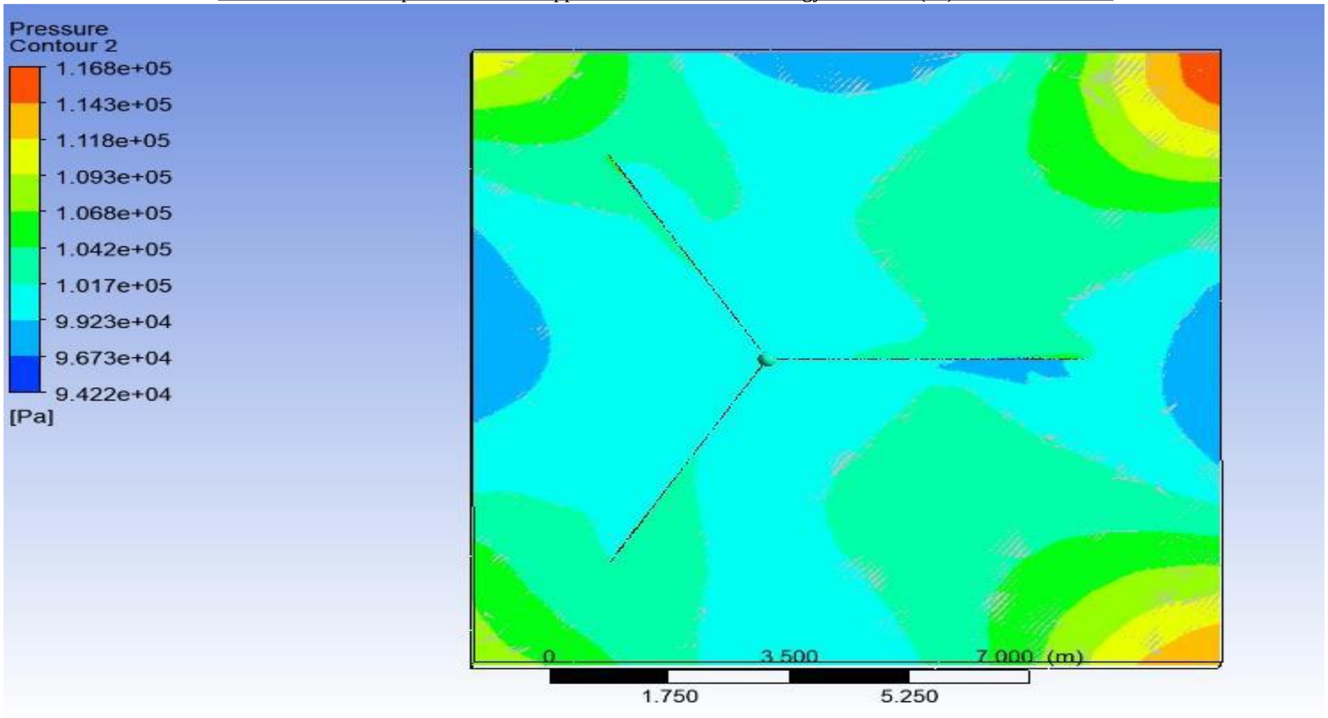

Fig.12 Front view of pressure distribution on the whole turbine

Further, the pressure distribution is also analyzed by using a side view plot distribution to observe the pressure variation on the blade of the designed model.

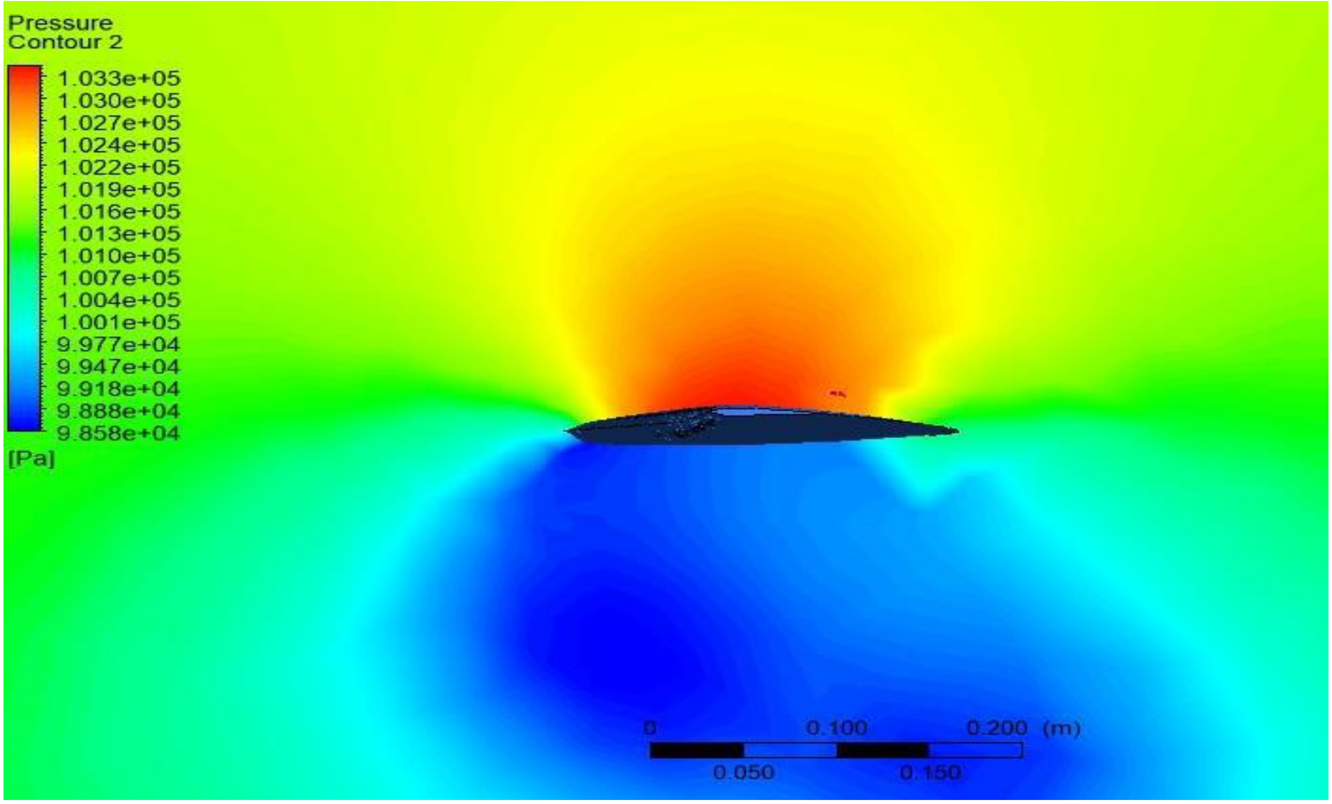

Fig.13 Pressure distribution on the blade of the designed model

It can be observed from Fig. 13 that in the upper red region of the blade the pressure is high, while the lower side of the blades shows the lower pressure so that it generates motion in the wind blade.

Conclusion

The current research has proposed a design for HAWT to satisfy the energy needs at the microscopic level in Pakistan. It is found that the maximum of TSR always relies on the number of blades in the wind turbine rotor. If the number of blades decreases, the wind turbine rotor rotates faster to extract the maximum power from wind. All the determined outcomes have been verified utilizing computational analysis. The wind turbine design is accomplished by using the specified conditions and the K-epsilon turbulence model. The simulation results have revealed that there exists a pressure difference between the upper and lower sides of the blade which generates the motion in the wind blade. Hence, these computations validate the proposed wind turbine design to provide a decentralized, sustainable and reliable energy framework.

ACKNOWLEDGEMENT

The authors are grateful to the University of Engineering and Technology Lahore, and all other institutes for providing facilities to accomplish current research work.

Reference

1. Asif M. Sustainable energy options for Pakistan. Renewable and Sustainable Energy Reviews, 2009, 13: 903-909.
2. Xu Q, Lin A, Cai Y, Ahmad N, Duan Y, Liu C. Numerical analysis of aerodynamic characteristics of exhaust passage with consideration of wet steam effect in a supercritical steam turbine. Energies, 2020, 13(7):1560.
3. Fawzy H, Zheng Q, Ahmad N, Jiang Y. Optimization of a Swirl with impingement compound cooling unit for a gas turbine blade leading edge. Energies, 2020, 13(1):210.
4. Abbas T, Bazmi A. A, Bhuttoo A. W, et al.
5. Greener energy: Issues and challenges for Pakistan solar energy prospective. Renewable and Sustainable Energy Reviews, 2014, 31: 258-269.
6. Ghaffar M. A. The energy supply situation in the rural sector of Pakistan and the potential of renewable energy technologies. Renewable Energy, 1995, 6(8): 941-976.
7. Mallawi K.Y, Badr M.A. A practical approach for selecting optimum wind rotors. Renewable Energy, 2003, 28: 803-822.
8. Reiche D, Bechnerger M. Policy differences in the promotion of renewable energies in the EU member states. Energy Policy, 2004, 32: 39-52.

9. Brondstead P, Holmes J .W, Sorensen B. F.
10. Wind rotor blade materials technology. European Sustainable Energy Review, 2008, 2: 36-41.
11. Stol K. A, Zhao W.X, Wright A.D. Individual blade pitch control for the controls advanced research turbine (CART). Journal of Solar Energy Engineering, 2006, 128: 498-505.
12. Reiche D, Bechnerger M. Policy differences in the promotion of renewable energies in the EU member states. Energy Policy, 2004, 32: 39-52.
13. Brondstead P, Holmes J W, Sorensen B F. Wind rotor blade materials technology. European Sustainable Energy Review, 2008, 2: 36-41.
14. Stol K A, Zhao W X, Wright A D. Individual blade pitch control for the controls advanced research turbine . Journal of Solar Energy Engineering, 2006, 128: 498-505.