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UTILIZATION OF MAXIMUM POWER IN AIRFOIL BLADE OF HORIZONTAL AXIS WIND TURBINE BY THE CONCEPT OF CFD ANALYSIS

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Abstract: Pollution free power production, quick installation and commissioning capability, less operation and maintenance cost and taking benefit of by means of free and renewable energies are all advantages of using wind turbines as an power generators. Along with these advantages, the main drawback of this source is the conditional nature of wind flow. Therefore, using reliable and efficient apparatus is necessary in order to get as much as energy from wind during the limited period of time that it flows strongly. Wind power is the fastest increasing renewable energy resource and wind power penetration in power systems increases at a significant rate. The high access of wind power into power systems in the present and near future will have several impacts on their planning and operation. A wind turbine transforms the kinetic energy in the wind to mechanical energy in a shaft and ultimately into electrical energy in a generator. Turbine blade is the mainly important part of any wind turbine. In this paper we consider single airfoil NACA 0018 and done CFD analysis at different blade angles 00,100,150 and 300 with constant wind velocity of 6 m/s. The analysis results show that blade angle 15º gives best possible power.

Keywords: Airfoil, Wind Speed, Air Density, Power of Wind, CFD, NACA, Angle of Attack, Lift Coefficient, Drag Coefficient.

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INTRODUCTION

Wind energy is now the second fastest-growing source of electricity in the world, with a global installed capacity of 486,790 MW at the end of 2016.Wind energy technologies use the energy in wind for practical purposes, such as generating electricity, charging batteries, pumping water, and grinding grain. Mechanical or electrical power is created through the kinetic energy of the wind. Wind power available is proportional to the cube of its speed, which means that the power available to a wind generator increases by a factor of eight if the wind speed doubles Kekezoğlu *et al.* (2015).Wind energy outshines all other renewable energy resources due to the recent technological improvements. Electrical energy generation from wind power has increased rapidly and due to the increased interest many studies on efficient wind turbine design have been performed Gilbert, (2004).

Wind turbines are mounted on a tower to capture the most energy. At 30 meters or more above ground, they can take advantage of faster and less turbulent wind. For the best utilization of wind turbines, they should be placed where wind speeds reach 16-20 mph and are at a height of 50 m. It is also important that utility-scale power plants are located near existing power lines and in the windiest sites available Kekezoğlu *et al.* (2015). The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.

Wind machine operates in an environment totally different than airplane wings characterized with continually changing wind speed and direction. Since the power contained in a moving air stream is proportional to the square of the rotor diameter and to the cube of the wind speed, the rotor blades must be carefully designed in order to optimally extract this power and convert it into torque that drives the electrical generator Chandrala *et al.* (2013).

Lift on a body is defined as the force on the body in a direction normal to the flow direction. Lift will only be present if the fluid incorporates a circulatory flow about the body such as that which exists about a spinning cylinder. The velocity above the body is increased and so the static pressure is reduced. The velocity beneath is slowed down, giving an increase in static pressure. So, there is a normal force upwards called the lift force. The drag on a body in an oncoming flow is defined as the force on the body in a direction parallel to the flow direction. For a windmill to operate efficiently the lift force should be high and drag force should be low. For small angles of attack, lift force is high and drag force is low. If the angles of attack (α) increases beyond a certain value, the lift force decreases and the drag force increases. So, the angle of attack plays a vital role James (2009).

Wind turbines work by the action of the relative wind, which creates aerodynamic forces on the rotating blades. These can usually be grouped into lift-like forces and drag-like forces. Lift forces operate through the generation of flow and do not involve large viscous losses in the flow and the associated loss of total head, while drag forces function through flow separation on the blade and the loss of total head Spera (1994).

The power efficiency of wind energy systems has a high impact in the economic analysis of this kind of renewable energies. The efficiency in these systems depends on many subsystems: blades, gearbox, electric generator and control (Hartwanger & Hovert, 2008).

To produce the power using wind energy, we use the rotating force which is generated by kinetic energy of wind. Therefore, the rotor is a main part of power making using wind kinetic energy. Particularly, an aerodynamic design of a rotor blade decides the efficiency of device for power production. Researches about the rotor blade have been studying all around the world. A variety of types of airfoils have been existing in wind power production. Regarding power generation, the kind of an airfoil should not to be changeable according to the fault and damage on the surface of an airfoil Kim *et al.* (2006).

METHODOLOGY

Airfoil System - An airfoil is the shape of a wing, blade, an airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. The nomenclatures of airfoil system are Chandrala *et al.* (2013).

(a) Chord length – length from the LE to the TE of a wing cross section that is parallel to the vertical axis of symmetry.
(b) Mean camber line – line halfway between the upper and lower surfaces.
(c) Leading edge (LE) - the front most point on the mean camber line.
(d) Trailing edge (TE) - the most rearward point on mean camber line.
(e) Camber – maximum distance between the mean camber line and the chord line, measured perpendicular to the chord line.
(f) 0 camber or uncambered - means the airfoil is symmetric above and below the chord line.
(g) Thickness – distance between upper surface and lower surface measured perpendicular to the mean camber line.

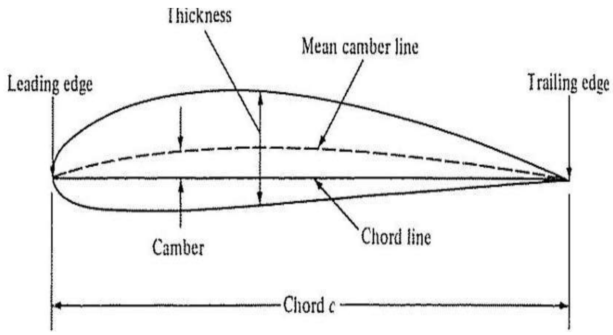

Fig. 1 Airfoil System

In this paper, NACA 0018 airfoil is used. The blade is made up of single airfoil. The chord length varies from throughout of its length (Patel & Hovert, 2013). For the analysis airfoil chord length 160 mm and span 290 mm are considered. In NACA four digit series (0018):

(i) First number is camber in percentage of chord (0).
(ii) Second number is location of maximum camber in tenths of chord measured from LE (0).
(iii) Last two digits give maximum thickness in percentage of chord (18).

One of the major challenges in this century is the efficient use of energy resources as well as the growing production of energy from renewable sources. There are several alternative forms of energy that have been explored and developed such as geothermal, solar, wind and hydroelectric power. The affordability and performance of renewable energy technologies is the key to ensure the availability to the mass market. Wind energy is produced from Wind turbine, in this paper, horizontal axis wind turbine is considered to study. Power produced from wind is given by following equation.

$$P_w = \frac{1}{2} \times \rho \times A \times u^3 \qquad (1)$$

where, P_w = Power of wind (W), ρ = Air density (Kg/m^3) (1.225 Kg/m^3), A = Area of segment of the wind being considered, and u = Undistributed wind speed (m/s).

Wind turbine power output varies with wind speed. So, if wind velocity is changed than power is also changed. So, constant power output is not obtained. To get optimum power output the blade design must be changed for constant speed. In this project, horizontal axis wind turbine blade is analyzed in Ansys software. NACA 0018 airfoil is selected for the analysis. The blade is made up of single airfoil. The chord length is varying throughout the blade. Analysis is done by changing the blade angle at 0°, 10°, 15°and 30° for different wind speed 6 m/s. Result can show that which blade angle give optimum power output for above wind speed.

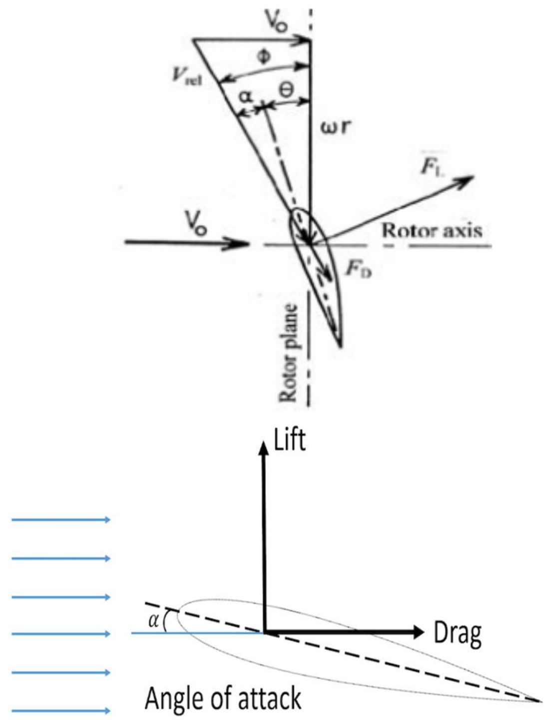

Fig. 2 Velocity and force diagram.

Design of horizontal axis wind turbine blade

The basic dimensions of the HAWT and another component have been determined from the basic calculation of the HAWT is explained as under. The velocity triangle of airfoil profile is used to calculate lift and drag forces which are shown in **Fig. 2.** The local wind angle (φ) is obtained by summation of blade angle (θ) and angle of attack (α) (Rajakumar & Ravindrann 2010; Hartwanger & Hovert, 2008).

For the calculations different angle of attack (AOA) is considered. Take α = -2, 0, 2, 4, 6, 8 .The angle of attack is considered only for linear region. NACA 0018 airfoil lift coefficient, drag coefficient and L/D ratio for different angle of attack is given in **Table 1**, which is obtained from design foil software and **Figs. 3–5**, shows it in graphical form.

As the angle of attack increases L/D ratios increase up to 10^0. After that L/D ratios will decreases. The critical angle of attack is the angle of attack which produces maximum lift coefficient. This is also called the stall angle of attack. Below the critical angle of attack, as the angle of attack increases, the lift coefficient increases.

Normally for most of the airfoils, the connection is similar. As the AOA increases drag also increases. As the AOA increases the C_L the coefficient of lift increases until it reaches a critical angle of attack. But as this happens drag also increases as C_D which is coefficient of induced drag increases.

Table 1. Angle of attack with lift and drag coefficient

AOA	LIFT	DRAG	L/D
-2	-0.25	0.0074	-33.8
0	0	0.0072	0
2	0.25	0.0073	34.2
4	0.499	0.008	62.4
6	0.748	0.0091	82.2
8	0.995	0.0106	93.9

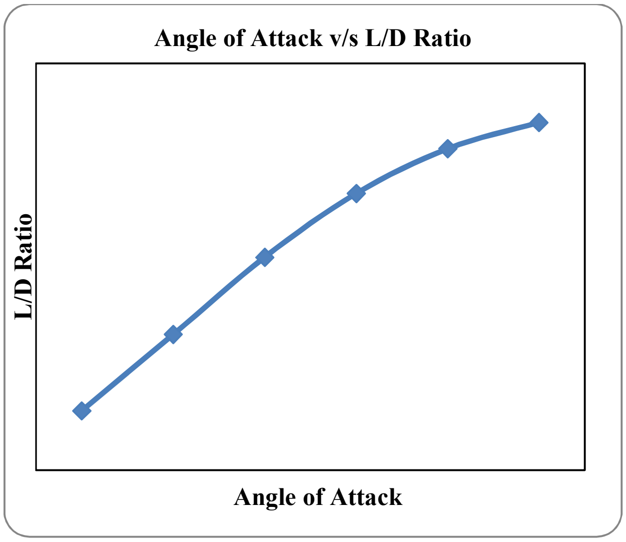

Fig. 3 Angle of attack v/s L/D ratios

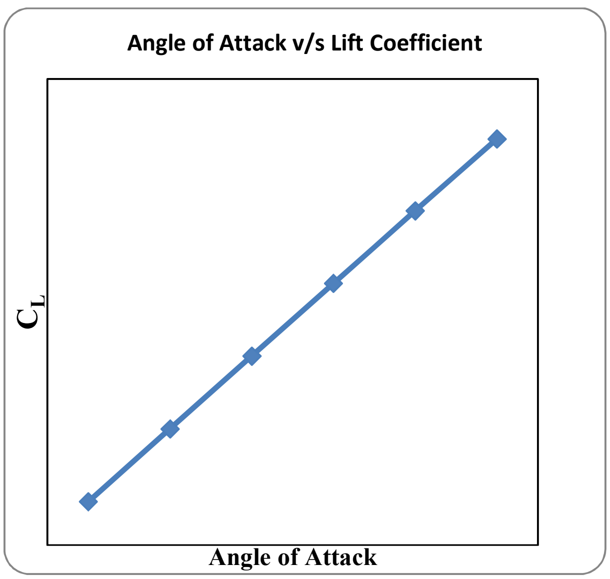

Fig. 4 Angle of attack v/s C_L

In **Fig. 6** angle of attack v/s lift, drag, L/D, pitch moment coefficient shows in one graph. The result of this graph was generated by experimental work, i.e. wind tunnel test data. For the validation of software work with experimental work, **Fig. 3-5** are compared with **Fig. 6** for linear region. Results are matched with experimental works. Hence, **Table 1** shows the accepted values of lift coefficient, drag coefficient and L/D ratio

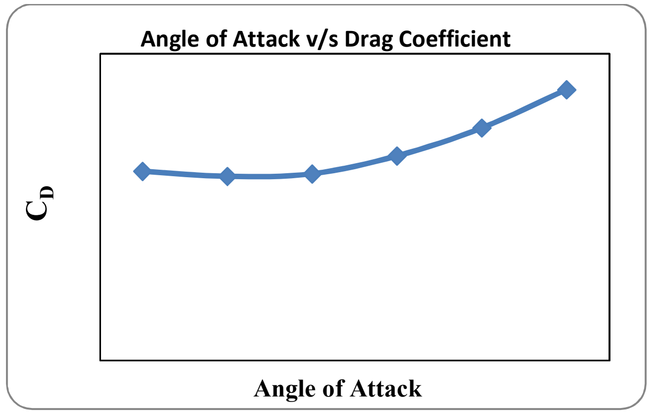

Fig. 5 Angle of attack v/s C_D ratios

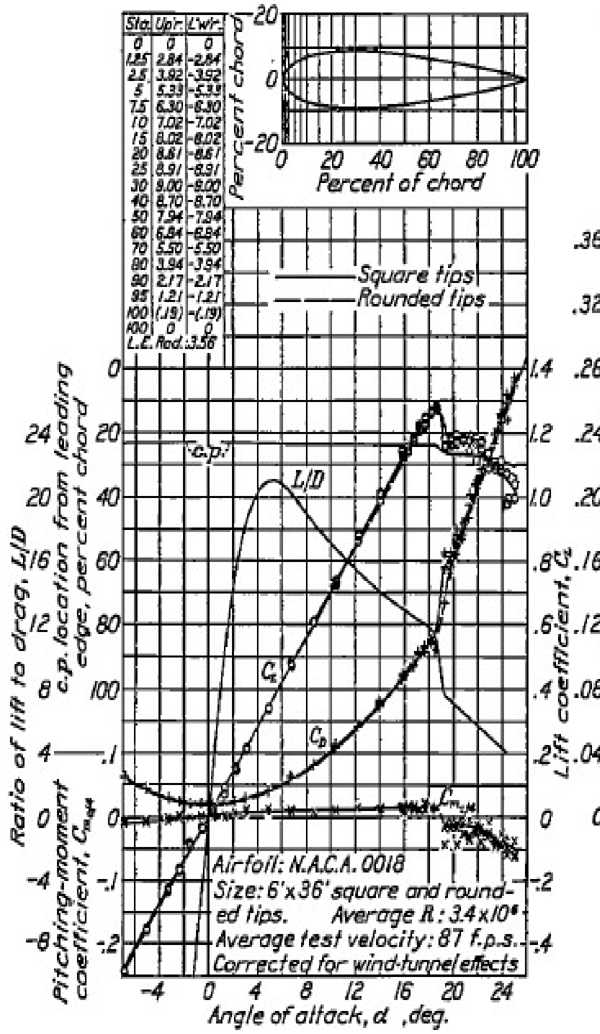

Fig. 6 Characteristics of NACA 0018 airfoil

Modelling of Horizontal Axis Wind Turbine Blade

After performing simple calculations, the modelling has been performed on the SOLIDWORKS and then after analysis work has been performed on the ANSYS. Prior to the following **Table 2** shows NACA 0018 airfoil coordinates.

Table 2. NACA 0018 Airfoil Coordinates.

X	Y	Z
1	0	0
0.95869	0.01037	0
0.88802	0.02394	0
0.80323	0.03881	0
0.71082	0.05337	0
0.6151	0.06656	0
0.51933	0.07752	0
0.42617	0.08543	0
0.33786	0.08956	0
0.25639	0.08934	0
0.1835	0.08448	0
0.12082	0.07499	0
0.0698	0.06122	0
0.03181	0.04374	0
0.00815	0.02317	0
0	0	0
0.00815	-0.0232	0
0.03181	-0.0437	0
0.0698	-0.0612	0
0.12082	-0.075	0
0.1835	-0.0845	0
0.25639	-0.0893	0
0.33786	-0.0896	0
0.42617	-0.0854	0
0.51933	-0.0775	0
0.6151	-0.0666	0
0.71082	-0.0534	0
0.80323	-0.0388	0
0.88802	-0.0239	0
0.95869	-0.0104	0
1	0	0

Excel file was saved in .text. So it can be imported a file in solid works. By multiplying this coordinates with chord length, coordinates at a particular chord length can be obtained.

Modeling of HAWT Blade in SOLIDWORKS

The analysis is done only for an element of blade. For that a part of blade is selected. To create profile of the blade using NACA 0018 profile coordinate which chord length is 160 mm. **Fig. 7** shows profile of airfoil. This airfoil is extruded airfoil up to 290 mm to make a blade element. **Fig. 8** shows extruded airfoil or blade element. This blade element is used for CFD analysis.

The **Fig. 9** shows extruded airfoil or blade element. This blade element is used for CFD analysis.CFD is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. After this cavity domain is created & it's saved in.IGES, .STEP file. The file is later opened in Ansys CFX for CFS analysis.

CFD Analysis of Horizontal Axis Wind Turbine Blade

(a) Create cavity model of horizontal axis wind turbine blade.
(b) Import cavity model .IGES file into ANSYS CFX.
(c) Generate geometry in ANSYS CFX.
(d) Meshing the geometry.
(e) ANSYS CFX for pre-processing.
(f) Create air domain.
(g) Define inlet.
(h) Define outlet.
(i) Define solver control criteria.

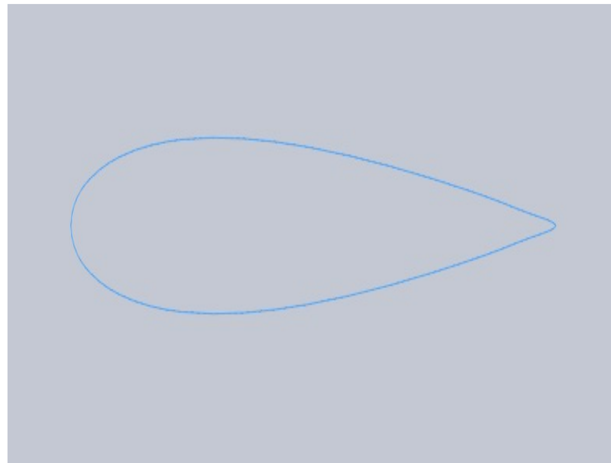

Fig. 7 NACA 0018 Airfoil in solid works

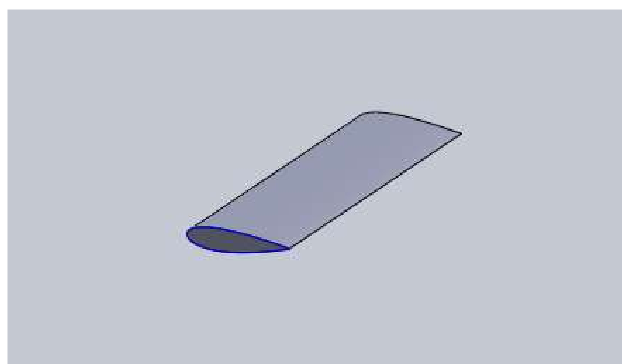

Fig. 8 Extrude airfoil

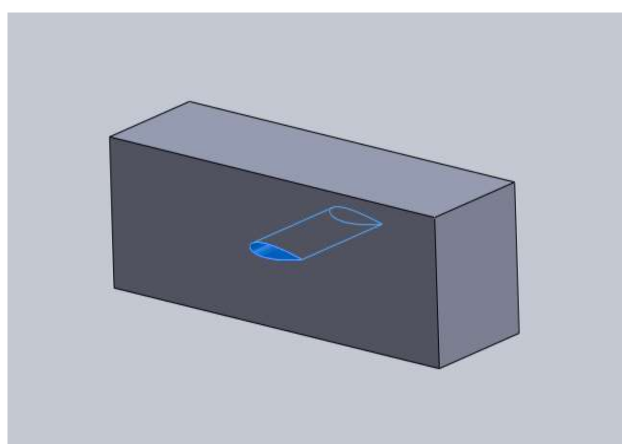

Fig. 9 Create cavity domain of above extruded airfoil.

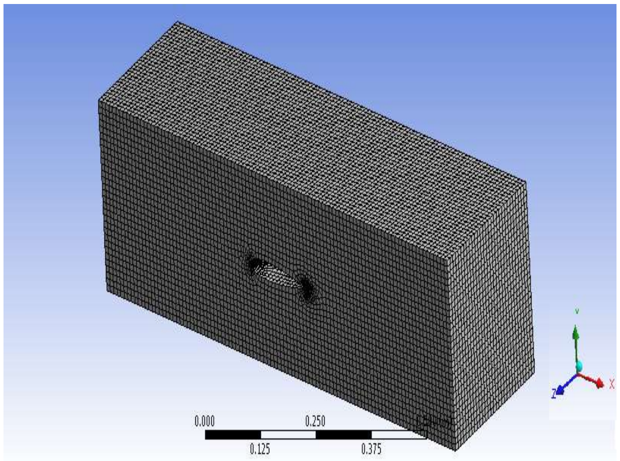

Fig. 10 Meshing of NACA 0018 airfoil

In the pre-processing fluid domain is selected. For the fluid air ideal gas is used. Here, domain is considered as stationary and heat transfer model is taken as total energy. K-ε turbulence model is used for simulation of airfoil segment in Ansys cfx fluid flow module to predict the flow regime. The K-ε model is one of the most common turbulence models. The first transported variable is turbulent kinetic energy; k. the second transported variable in this case is the turbulent dissipation factor ε. The latter is a variable that determines the scale of the turbulence, whereas the first variable, k, determines the energy in the turbulence Chandrala *et al.* (2013).

NACA 0018 airfoil CFD analysis result for blade angle 0° to 30°

0° Blade angle: Velocity contoure for 6 m/s velocity & 0° Blade Angle is showed in **Fig. 11**.

100 Blade angle: Velocity contoure for 6 m/s velocity & 100 Blade Angle is showed in **Fig. 12**.

15° Blade angle: Velocity contoure for 6 m/s velocity & 15° Blade Angle is showed in **Fig. 13**.

30° Blade angle: Velocity contoure for 6 m/s velocity & 30° Blade Angle is showed in **Fig. 14**.

From the above **Table 3**, as the position angle of the blade changing from 0^0 to the 30^0, power output is also changed Which is shown in **Fig. 15.**

Table 3. Domain condition

Domain Type	Fluid Domain
Fluid	Air Ideal Gas
Domain Motion	Stationary
Heat Transfer Model	Total Energy
Turbulence Model	$K - \mathcal{E}$ Model

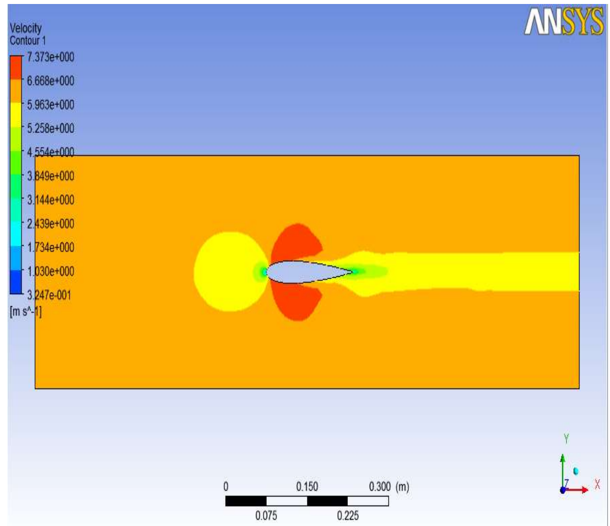

Fig. 11 velocity contours for 6 m/s wind velocity

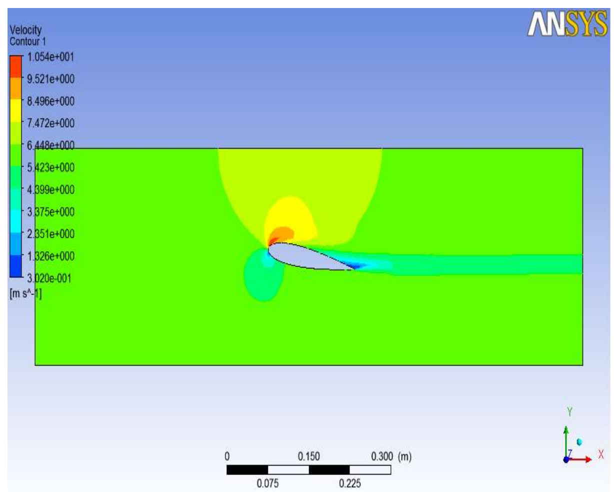

Fig. 12 velocity contours for 6 m/s wind velocity

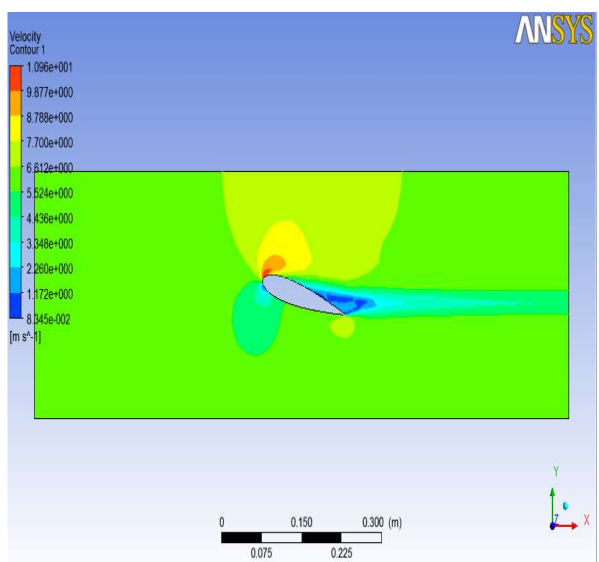

Fig. 13 velocity contours for 6 m/s wind velocity.

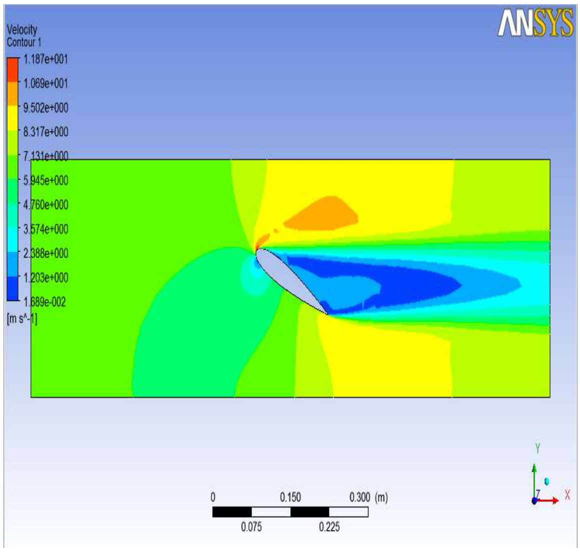

Fig. 14 velocity contour for 6 m/s wind velocity.

RESULTS

This work is an attempt to advance renewable energies by developing a detailed CFD analysis of the airfoil of a horizontal axis wind turbine blade. The result produced by the simulation is a small contribution to the renewable energy field. Specifically this work represents CFD analysis of NACA 0018 airfoil for HAWT blade. The model includes a detailed description of the velocity field, pressure field and power produced. Analysis of blade has been done for 0°, 10°, 15° and 30° angles for 6 m/s wind speed. After performing the analysis of the horizontal axis wind turbine summary of the results is mentioned in below **Table 4**.

Table 4. Effect of Power in various angle of blade for 6 m/s wind speed.

Sr. No	Blade Angle	Velocity (m/s)	Density (kg/m^3)	Power (W)
1	0^0	5.96	1.225	46681
2	10^0	6.45	1.225	59168
3	15^0	6.61	1.225	63681
4	30^0	5.94	1.225	46213

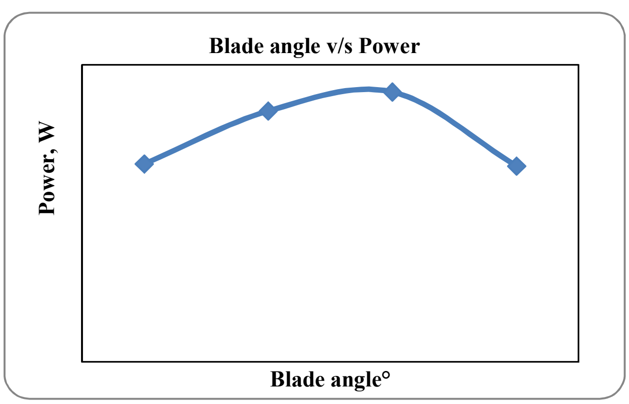

Fig. 15 powers in various angle of blade at 6 m/s wind speed

CONCLUSION

This work is an attempt to advance renewable energies by developing a detailed CFD analysis of the airfoil of a horizontal axis wind turbine blade. The result produced by the simulation is a small contribution to the renewable energy field. Specifically this work represents CFD analysis of NACA 0018 airfoil for HAWT blade. The model includes a detailed description of the velocity field, pressure field and power produced. Analysis of blade has been done for 0^0,10^0,15^0 and 30^0 angles for 6 m/s wind speed. From the result of this analysis the optimum power output have been achieved 63681 W at an angle of 15^0 for 6 m/s speed. CFD analysis is good tool to replace costly experimental setups and works. Wind tunnel testing is a time consuming process. CFD analysis helps to change or modify the design.

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