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Horizontal Axial Wind Turbine Blade Design Using Ansys Fluent

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***Abstract* — The concern over climate change and greenhouse gas emission from conventional fossil fuelled system is alarming in the ears of researchers. Several efforts to proffer solution to this development are gearing toward the sustainability and promotion of renewable technologies to erase out machineries capable of polluting the environment has been the centre of research. Thus, present study is one route for the replacement of fossil fuel engines with natural wind generated machine popularly called wind turbine which has the same and equal capacity with its contemporaries. Therefore, the design process of wind turbine blade with Ansys Fluent Computational Fluid Dynamics (CFD) is the applied technique for this study. Results obtained satisfy all conditions of wind turbine blade design. It attests a low value of solidity of 0.0398 with 16° angle of attack yielding 0.711 and 0.2 lift and drag coefficients respectively (C_L & C_D); this is in conformity with the open literature. These simulated values are capable of regulating the forces acting on the blade. Again established results in the graphical plot shows that output power of 250KW is produced with small wind speed of 80Km/h at specified blade angle of 5°. Different iterative test results are shown to validate the concept and phenomenon of the lift and drag coefficients. Therefore results confirm that the designed blade is capable of producing optimum electrical power which is the target of the study. Hence, the aerodynamics blade design of horizontal axial wind turbine using Ansys Fluent CFD tool is practically viable.**

Keywords— Angle of Attack, C_D, CFD, C_L, Pitch angle, Wind Speed, Wind Turbine Blade.

I. INTRODUCTION

The effects of modern civilization on the environment and dwindling of climate change has spur series of un-relented research in developing alternative energy sources. This will help minimize the depletion of the ozone layer and save our planet from the adverse effects of high dependency on the black gold-crude oil. Thus, the products of this black gold such as the un-burnt exhaust gases from engines, the exploration of oil and gas leading to gas flaring and other petroleum activities is capable of melting the glaciers and the poles. This results to extreme weather condition, expulsion of animals and plants and wild spread of diseases in the environment. One successful route to move out of this epidemic is to embrace an alternative energy source which is sustainable enough to improve the environment free of all hazardous effects contributed by the use of fossil fuels to energize our machineries for energy production.

Previous studies unveil series of renewable energy sources ranging from biomass, solar system, geothermal, hydro system and wind energy capable of alleviating the total dependence on fossil fuel. To prevent destruction of the environment, generation of techno-industrial and socio-economic welfare will create sustainability in the energy sector to decrease the greenhouse gas emissions [1,2]. However, the method of cultivation of these energy sources in replacing the fossil fuel is the subject of the current research. Among the various fields of renewable energy; wind energy source is selected as the focal point of study. Wind energy is an abundant resource given by nature free of cost.

Hence to maximize optimum kinetic energy from the wind speed, researchers have carried out several efforts on the design of effective blade geometry. In a reviewed literature according to [3]; along a rotor blade there are different sections or integral parts that makes the full blade. In order to improve the efficiency, modern rotor blade needs more complicated and efficient designs. However, the main parameters that control the behaviour of torque and efficiency curves for each configuration are the number of rotor blades, radial distribution of the chord, aerodynamic characteristics and twist angle distribution [4, 5, 6]. From the energy and structural point of view, the flow behaviour behind the rotor is important in the operation. This influences and increases the power distribution of the blade in the radial direction, but the power coefficient decreases among the region near the tip due to vortex generation, thus this phenomenon can be significantly reduced by modifying the tip shape [7].

Previous research focuses primarily on reducing the size of the turbine to achieve lower production and installation costs. However; the new design trends in order of importance are increasing efficiency, increasing resistance to dynamic loads, mass reduction and reduction of acoustic noise emission [8, 9]. Currently, the trend of research for wind turbine blade design has moved from numerical and experimental base to computer program codes to minimize and customize huge expenses. Therefore, the present study is to analyze the performance of wind turbine blade with aerodynamic and structural integrity challenges. Ansys Fluent CFD computer simulation tool which has high potentials to determine the effectiveness of airfoils and efficiency of turbine blades is used for the research. This tool provides a qualitative and quantitative prediction with confidence in impact of fluid flow over the wine turbine blade. The aerofoil throughout the design study uses discretization, and pre/post-processing utilities solvers of the software tool. The purpose is to tackle design problems through the optimization of the present technology and improvement in the efficiency of the wind turbines for long-term sustainability.

II. MATERIALS AND METHODS

To model an accurate turbine blade, sample of NACA4415 aerofoil data is used. This contains information about the coordinates of the aerofoil provided in table 1 where the coordinates represents the *x* and *y* positions around the chord. Thus, a Matlab code is used to plot the coordinates of the aerofoil and is presented in figure 1. Also, information about the sectional twist along the blade and the thickness of the blade is required in order to perform a three dimensional modeling of the wind turbine blade. The aerofoil shape helps in modeling the geometry of the blade with the aid of the parameters available in table 2. During this process, NACA4415 aerofoils with various chord lengths (m) at different radial locations (r) along the blade and the corresponding angle of twist are modeled and assembled together to make an entire blade surface.

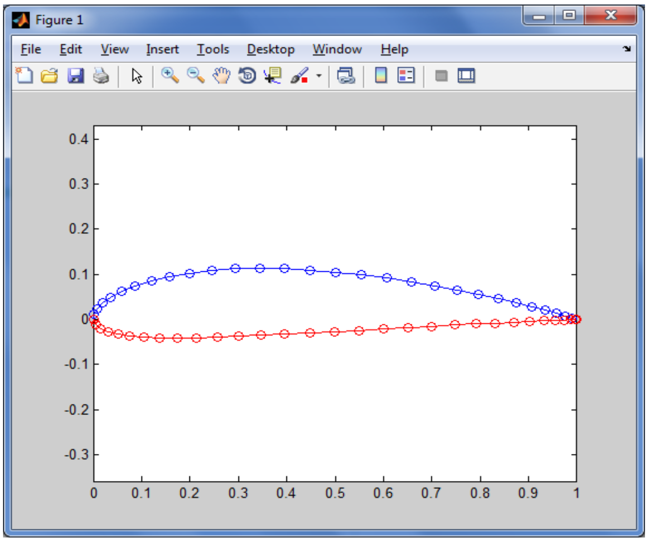

Figure 1 Matlab Plot of the aerofoil profile

Table 1 Coordinates of NACA 4415 aerofoil section

UPPER SURFACE		LOWER SURFACE	
x/c	y/c	x/c	y/c
1.00000	0.00156	0.99979	-0.00156
0.96946	0.01100	0.96771	-0.00284
0.93865	0.02002	0.93576	-0.00415
0.90781	0.02863	0.90397	-0.00505
0.87697	0.03682	0.87236	-0.00689
0.84617	0.04460	0.84095	-0.00833
0.81545	0.05198	0.80978	-0.00981
0.78483	0.05814	0.77887	-0.01134
0.75437	0.06550	0.74824	-0.01292
0.72408	0.07164	0.71793	-0.01454
0.69400	0.07738	0.68795	-0.01619
0.66418	0.08270	0.65834	-0.01787
0.63463	0.08762	0.62911	-0.01956
0.60540	0.09211	0.60029	-0.02126
0.57652	0.09620	0.57191	-0.02294
0.54802	0.09986	0.54399	-0.02460
0.51994	0.10311	0.51654	-0.02622
0.49231	0.10594	0.48960	-0.02778
0.46515	0.10835	0.46319	-0.02926
0.43851	0.11034	0.43732	-0.03066
0.41241	0.11192	0.41201	-0.03195
0.38662	0.11306	0.38756	-0.03314
0.36119	0.11363	0.36396	-0.03433
0.33640	0.11364	0.34097	-0.03552
0.31228	0.11310	0.31861	-0.03667
0.28888	0.11203	0.29690	-0.03776
0.26621	0.11046	0.27584	-0.03878
0.24433	0.10842	0.25544	-0.03968
0.22324	0.10592	0.23572	-0.04046
0.20299	0.10302	0.21669	-0.04109
0.18360	0.09972	0.19836	-0.04156
0.16508	0.09607	0.18074	-0.04185
0.14748	0.09209	0.16385	-0.04194
0.13080	0.08782	0.14770	-0.04181
0.11507	0.08329	0.13231	-0.04147
0.10030	0.07854	0.11768	-0.04088
0.08651	0.07360	0.10383	-0.04006
0.07370	0.06850	0.09078	-0.03898
0.06190	0.06327	0.07854	-0.03765
0.05110	0.05794	0.06712	-0.03604
0.04133	0.05255	0.05655	-0.03417
0.03257	0.04712	0.04683	-0.03203
0.02484	0.04168	0.03798	-0.02960
0.01814	0.03624	0.03001	-0.02690
0.01247	0.03084	0.02294	-0.02392
0.00738	0.02549	0.01154	-0.01709
0.00164	0.01501	0.00386	-0.00912
0.00000	0.00000	0.00000	0.00000

Table 2 Designed Blade Specifications

Property	Value
Blade Length (m)	8.645
Hub Radius (m)	0.782
Tip Radius (m)	8.978
Blade Coning Angle	7.00 deg
Total Blade Twist Angle	6.54 deg
Operational pitch Settling	-1.0 deg
Root (inboard) Airfoil	NACA 4415
Mid-Span Airfoil	NACA 4415
Tip-(outboard) airfoil	S809
Maximum Chord (m)	1.0402
Tip chord	0.386
Number of Blades	2
Rotor Radius (m)	9.246
Hub Radius (m)	0.542
Hub height (m)	35.216

In order to perfect the modeling process, the aerofoil data plotted in Matlab code saved in picture format were imported to solidworks interface as a guide for accurate modeling. A spline tool in sketch is used to trace the profile of the aerofoil to obtain profiles of different lengths. This follows dimensioning of the traced profile to vary the lengths of the different aerofoils obtained from the picture sketch for comparison with NACA4415 profile obtained from the open literature to check for conformity. The advantage of using this sketch tool is to enable the complex geometry of the aerofoil to be creatively captured in the design process of the model without compromising with the traditional geometry of the aerofoil. Thus, figure 2 shows complete sketch of the aerofoil in solidworks. The profile of the defined aerofoil is used to ease the modeling process of the turbine blade under study in figure 3 for force analysis using CFD Simulation.

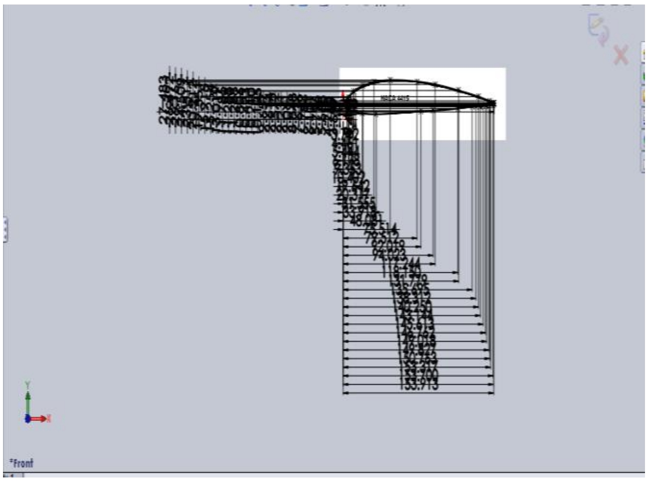

Figure 2 Complete aerofoil sketch

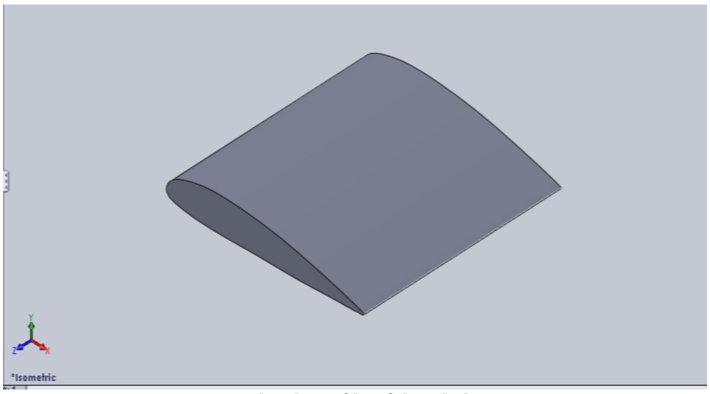

Figure 3 Sketch Profile of the Blade

III. BLADE CURVATURE ANALYSIS

Thus, before the final modeling process, a curvature or twist analysis is carried out on the sketch profile. This analysis is to help obtain the points of inflexion and to ensure that the curves used in the profile sketch is identical to the intended profile of the NACA4415 as obtained in the previous literatures. This also ensures manual meshing of the aerofoil where the curvature analysis gives an ideal concept of how the mesh lines should be drawn especially close to the boundary of the profile. However, this process becomes necessary and alternative to meshing because it stands as a check to objectify accurate blade meshing. Meanwhile, figure 4 is diagrammatic illustration of curvature analysis of the blade while figure 5 represents the final model of the wind turbine blade under study.

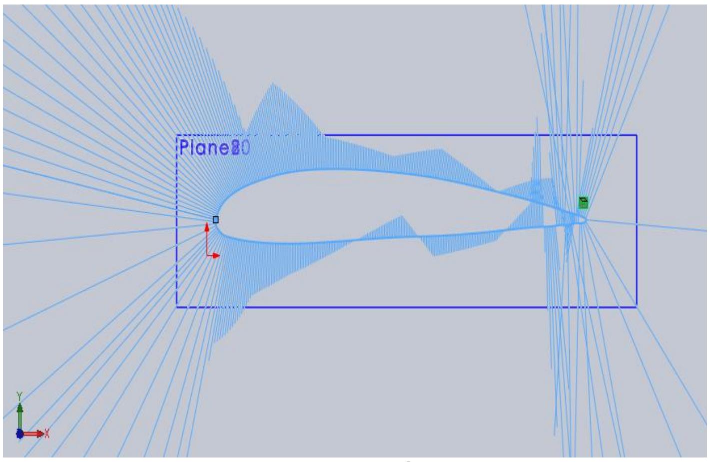

Figure 4 Curvature Analysis

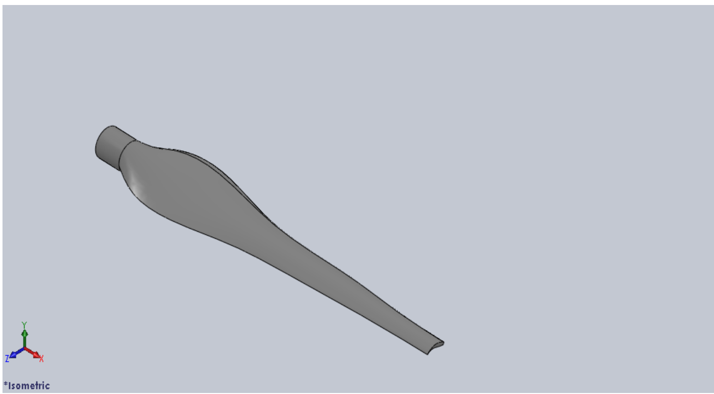

Figure 5 Model of the Turbine Blade

IV. CFD BLADE SIMULATION USING ANSYS FLUENT

CFD analysis is carried out on the modeled wind turbine blade, followed by blade meshing using Ansys Fluent package. Fluent is then used to analyze the flow of the blade to test for blade aerodynamics and flow characteristics of the wind turbine. This will determine the possible amount of wind energy the turbine blades are capable of converting to mechanical energy which may be synchronized in the generator for conceivable electrical energy or other source of useful energy at end use. The solver is further employed to analyze the boundary conditions of the blade in the computational domain representing wind tunnel in real concept to test the flow characteristics of the wine turbine blades and it is shown in figure 6.

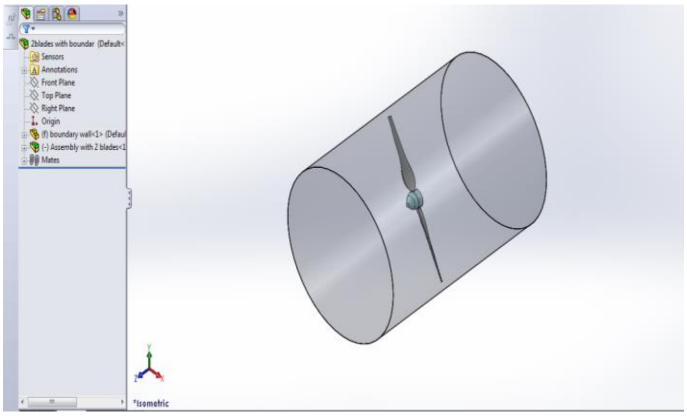

Figure 6 Computational Domain of 2 blades Assembly

V. RESULT PRESENTATION

At the end of the simulation process of the modelled blade with CFD Ansys Fluent, the following results are achieved and presented in figures 7–10. They are graphical plots of lift and drag coefficients against angle of attack, glide ratio versus angle of attack, power and bending moment against wind speed respectively. Also iterative test for lift, drag and moment coefficients to determine the peak performance of these parameters is evaluated in figures 11 – 13.

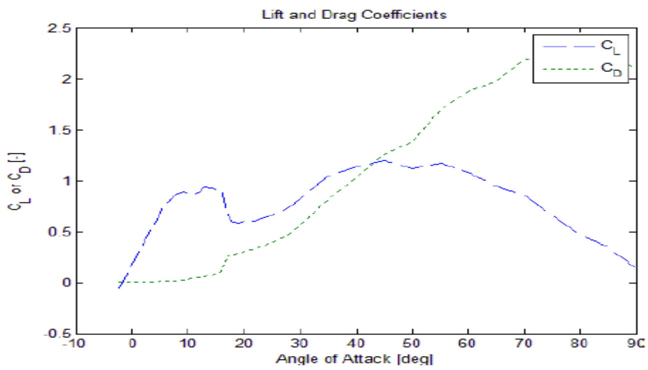

Figure 7 Lift and Drag Coefficient for Designed blade

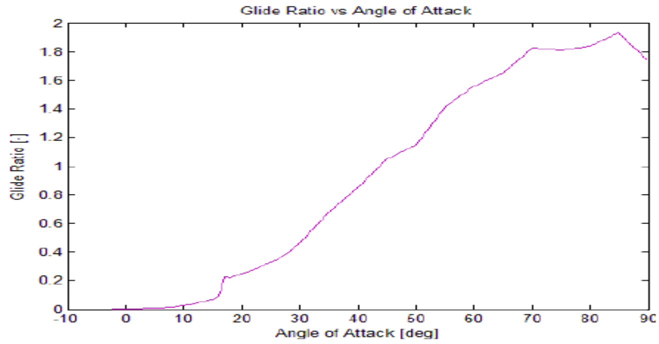

Figure 8 Glide Ratios for Modeled Blade

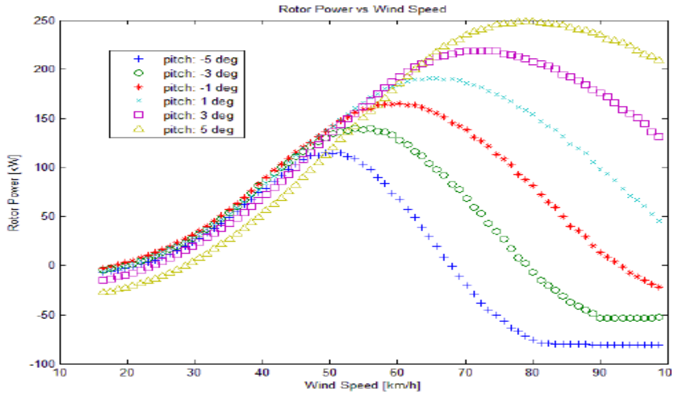

Figure 9 Power against Wind speed of rotor

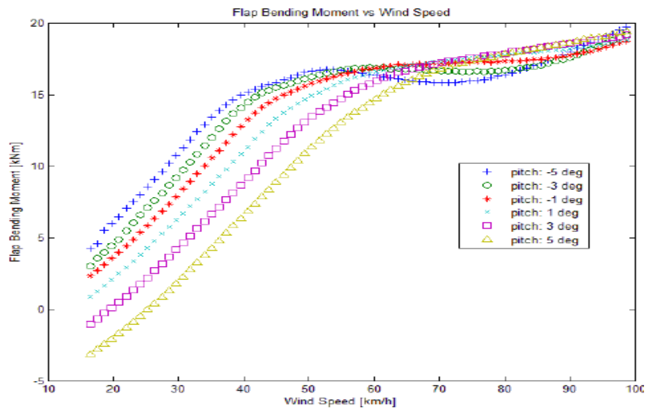

Figure 10 Bending Moment Against Wind Speed

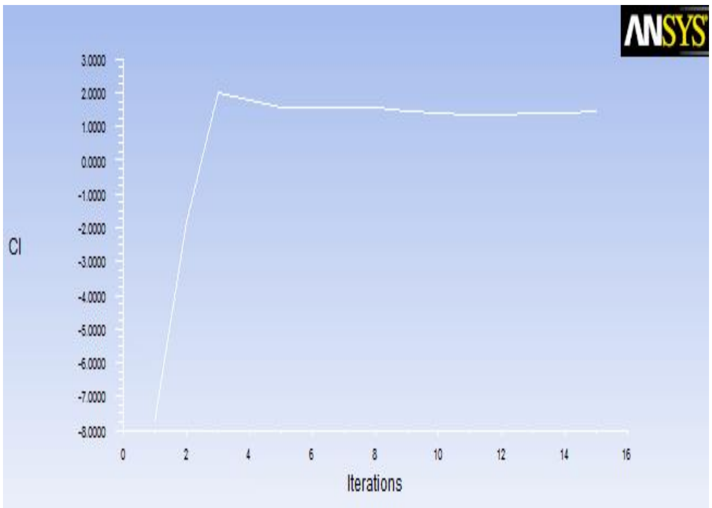

Figure 11 Lift Coefficient for the Designed Blade

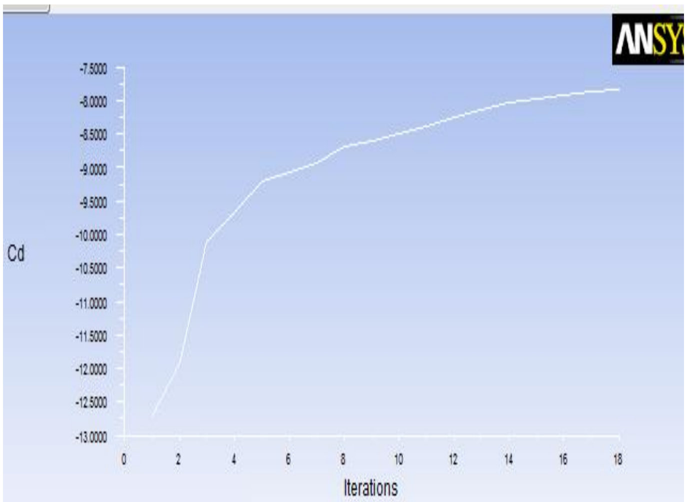

Figure 12 Drag Coefficient for the Designed Blade

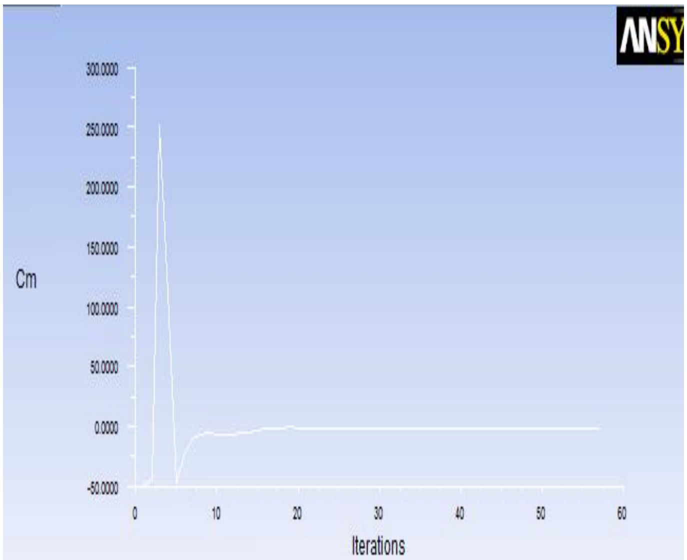

Figure 13 Moment Coefficient for the Designed Blade

VI. Result Discussion

The geometry and configuration of the modeled blade uses the NACA 4415 aerofoil data. The profile is uniquely defined by the coordinates that appears on table 1. Evaluated minimum value of solidity (σ = 0.0398) at a peak tip radius of 8.978m with affordable wind speed supply is of 6.54° blade twist angle for 2 blades connection with simulation assumption that the tip loss and drag coefficient are zero is used for the simulation. As established in the open literature, horizontal axial wind turbine is lift force based wind turbine with very good performance, therefore to achieve high value of lift force, the lift coefficient should be higher than the drag coefficient at a given angle of attack.

Hence, figure 7 satisfied this phenomenon where the angle of attack (α) of the modeled blade is 16°; corresponding to lift coefficient (C_L) of 0.711 and drag coefficient (C_D) of 0.2. This plot shows that for low values of angle of attack the airfoil successfully produces a large amount of lift coefficient with little drag coefficient. Also at around $\alpha = 16°$; there is an occurrence known as variation of glide ratio of the modelled aerofoil with different angle of attacks as illustrated in Figure 8. It is obvious that the glide ratio corresponding to 16° angle of attack is less than 0.2; this is a preferable design parameter for blade airfoils as validated in the reviewed literature. Thus, the low glide ratio, angle of attack, and lift coefficient with corresponding minimum values for glide ratio is chosen as α_{design} and $C_{Ldesign}$ using the airfoil data file. The change of the performance parameters of the designed rotor such as power, bending moment with respect to the wind speed at different pitch angles is given in figures 9 and 10 respectively. The maximum power and bending moment of the designed blade will be accomplished before pitching occurs when the wind speed exceeds the designed wind speed of the aerofoil. Pitching makes the turbine not to run too fast, therefore damage to the turbine at high speed is avoided. Meanwhile, the highest power of the designed blade is obtained at 5° with output rotor power of 250kw corresponding to 80Km/h of wind speed. Whereas, the bending moment yields at the peak is 3° and 5° respectively with the same range of wind speed.

Figures 11 and 12 shows the lift and drag coefficients with respect to iterations. As seen in various figures, the lift coefficient increases gradually and reaches a maximum value at 18 iterations; while the drag coefficient reaches its maximum value at a time-step of 2 iterations. This is also is a confirmatory simulation result which attests that the lift coefficient should be of higher value than the drag coefficient for a good output power and better performance. Thus, figure 13 shows the rise and fall of the moment coefficient with respect to iterations. It reaches its peak and gradually reduces at 5 iterations and maintains constant moment coefficient as the simulation tends to the end.

VII. CONCLUSION

The study is justifiable since simulation of the blade yields low solidity result producing optimum electrical power energy in wind turbine is in conformity with the reviewed literature. Again established results validates the position of horizontal axial wind turbine as a lift force based turbine with high efficiency in power generation because simulation attests low drag coefficient than lift coefficient at a given angle of attack. Thus, this assures preferable good design parameters for the blade because it is obvious that the achieved low glide ratio will matches the design requirements. It also creates smooth calculation of aerodynamic forces on each element of the blade using the lift and drag coefficient result developed from the CFD simulations. Simulation results for power production confirm high value of rotor output power against small amount of wind speed used in the process. Therefore, Study verifies the accuracy of this simulation tool acceptable and good method for fluid dynamics simulations. However, users are allowed to study the aerodynamics of various geometries at different physical settings to get true feelings of how the specific airfoil might behave in real world applications

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REFERENCE

[1] T.J. Ajoko, and T. A. Kilakime, "Generation of Power Through Hydrogen – Oxygen Fuel Cells", Research *Inventy: International Journal of Engineering and Science*, Vol.4, Issue 10, pp. 56-62, 2014.

[2] O. Margrét, "A General Description and Comparison of Horizontal Axial Wind Turbines and Vertical Axis Wind Turbines", School of Engineering and Natural Sciences University of Iceland, Reykjavik, (MSc Thesis), 2014.

[3] C. Han, "Aerodynamics Analysis of Small Horizontal Axis Wind Turbine Blades by Using 2D and 3D CFD Modelling," UCLAN, Preston, England, pp. 1, 2011.

[4] S. Qiyue, "Design, Fabrication, and Testing of a New Small Wind Turbine Blade", University of Guelph, Ontario, Canada, (MSc Thesis), 2012.

[5] K. Chris, F. Austin, K. Paul, and M. Wael, "A CFD Study of Wind Turbine Aerodynamics", *Proceedings of the American Society for Engineering Education (ASEE)*, North Central Section Conference, 2012.

[6] P. Hardik, and D. Sanat, "Performance Prediction of Horizontal Axial Wind Turbine Blade", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 2, Issue 5, 2013.

[7] W. Zhang, C. D. Markfor, and F. Porte-Agel, "Near-Wake Flow Structure Downwind of a Wind Turbine in a Turbulent Boundary Layer," *Experiments In Fluids*, Vol. 52, No. 5, pp. 1219-1235, 2012.

[8] T. V. Miguel, V. D. C. Marcelino, A. F. Juan, A. M. P. Luis, and T. E. Guilibaldo, "Design and Experimentation of a 1 MW Horizontal Axial Wind Turbine," *Journal of Power and Energy Engineering*, pp. 9-16, 2014.

[9] K. Maki, R. Sbragio, and N. Vlahopoulos, "System Design of a Wind Turbine Using a Multi-Level Optimization Approach," *Renewable Energy*, Vol. 43, pp. 101- 110, 2012.