International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 346-353 www.ijaem.net ISSN: 2395-5252

"Design and Optimization of Wind Turbine Blade"

[1.1] Miss. Achal Ravindra Gole, [1.2] Prof. P. J. Bhadange

[1.1] Miss. Achal Ravindra Gole, DR. Sau. KamaltaiGawai Institute of Engineering & Technology
[1.2] Prof. P. J. Bhadange DR. Sau. KamaltaiGawai Institute of Engineering & Technology

Date of Submission: 01-04-2023 Date of Acceptance: 10-04-2023

ABSTRACT: -Power generation is one of the most critical issues facing the world today, and it must be addressed with a high level of scientific reasoning and in-depth knowledge of energy sources. Hydropower plants, solar power plants, solar thermal power plants, and, most importantly, wind turbines are examples of renewable energy sources. As a result, harnessing and utilising the wind's energy is critical. The development of horizontal axis wind turbines (HAWTs) for small-scale applications is critical. A six-bladed wind turbine system with airfoils Gottingen 364,384,428,480, and 682 was used in the study. Key factors such as lift, drag, and stall of the airfoil are studied using design knowledge of on airfoils, and the twist of the blade segments is precisely designed.As a result, the blades for a six-bladed wind turbine system are designed for the optimal coefficient of lift value using Q-blade software and careful consideration at each location. Furthermore, the wind turbine's aerodynamic parameters, such as drag force, lift force, coefficient of drag, coefficient of lift, and lift to drag ratio, are calculated using Computational Fluid Dynamics (CFD). The flow pattern in two functional forms is used to calculate the output parameters, which are then solved for the wind flow over the blade in an enclosed medium using the appropriate procedure of the K-method. This method provides the highest level of accuracy in performing the analysis while also producing a very detailed output result.To forecast the performance of blades at low wind velocities, the six-bladed wind turbine system is validated using Numerical Study Computational Fluid Dynamics (CFD) using standard software (ANSYS-FLUENT). The analysis parameters are thoroughly examined and compared to the IEC-61400 Standard for small wind turbine systems. The wind designed input is the average wind velocity at hub height of 3m/s, and the proposed six-bladed wind turbine for each airfoil is carried out for analysis. It was investigated a six-bladed wind turbine system with Gottingen airfoils 364,384,428,480, and 682.

Key Words-Gottingen,MRF,Mesh,Contour,K-ϵ**.**

I INTRODUCTION

Wind energy is a useful source of renewable energy that involves the exercise of air inflow through wind turbines to automatic power creators for electric power. Wind power has been used in the form of windmills to thresh grains and pump water since before the Industrial Revolution. The gradational and unrelenting advancement of this technology has resulted in the proliferation of power-generating massive wind turbines that we see today. Wind turbines, for the most part, are massive in size, noisy, and require a large amount of space to function. This calls for the installation of wind turbines in uninhabited pastoral areas that are distributed by a strong wind inflow.Miniature breeze turbines can assist with managing down high power expenses and give a guard against truly adding power requests. A small wind turbine would be a practical and wise solution to the problems with electricity in remote parts of India, reducing our reliance on fossil fuels and avoiding hothouse feasts. A small wind energy system can cut a customer's electricity bill by 50 to 60 percent, depending on the original wind resource and mileage rates. It tends to be introduced as an independent framework, excepting the significant expense of stretching out mileage electrical cables to a remote position, or it very well may be associated with the power lattice, empowering the client to distribute excess capacity to the network or purchase new power when requested through a back metering framework. within the wind turbine's lifespan is vengeance on capital expenditure. Effective blades and a generator that would indeed produce energy at veritably low wind 2 speed are required due to the fact that a significant portion of the Indian land will not be suitable for the use of traditional windmills due to low wind pets. Considering India's veritable high transmission losses, locating the turbine close to the power consumption location might be an achievable outcome.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 346-353 www.ijaem.net ISSN: 2395-5252

• To make a breeze turbine that is both practical and produces a powerful result.
• To plan the sharp edge so it has an extraordinary self-beginning limit at extremely low wind speeds, and to play out a consistent state examination for the different edges demonstrated utilizing ANSYS 14.5.
• Lead an examination of different airfoil edges and select the most productive one for the last cutting edges.

Make the breeze turbine and subjugation the hypothetical qualities to the experimental outcomes. Douvi Eleni etal.(2012) made a concentrate on the examination of the two-layered subsonic inflow over a Public Warning Panel for Flying(NACA) 0012 airfoil at vivid approaches and working at a Reynolds number of 3 × 106 and he made sense of the geste of the review. The inflow was accomplished by working the steadystate administering conditions of toughness and incitement preservation joined with one of three choppiness models (Spalart-Allmaras, feasible and shear pressure transport(SST)). This expects to the affirmation of the models through the examination of the guesses and the free field trial measures for the named airfoil. McKittrick et al(2001) gave a nitty gritty report on measuring the CFD ways and it's set up CFD strategy's can really visualize the freight qualities of wind turbines and it's sensible to utilize pressure circulations achieved from CFD calculations as freight conditions to This work pushed two regions in computational liquid elements(CFD) which bear for disquisition change point vaticination and choppiness displaying. The laminar to violent progress point was displayed to come by precise outcomes for the drag measure at beautiful Reynolds figures.

Karna Patel etal.(2014) made a short report on CFD examination of an airfoil and he gave data on relationship of drag, life and powers and it influence on airfoils. From the review, it's obvious to find drag and lift powers utilizing CFD philosophy. The examination of the two-layered subsonic inflow over a NACA 0012 airfoil at bright approaches and working at a Reynolds number of 3 × E 06 is made and the CFD reproduction results show close concurrence with those of the preliminaries, thusly proposing a reliable volition to trial framework in deciding drag and lift. He likewise made sense of about the breeze nest testing framework to decide airfoil lift and drag powers where the interaction is moderately relentless and costly farther than CFD ways. thusly, affirmation of the investigation work has gone through intelligent framework likewise affirmation by exploratory testing.

Kevin Cox and Andreas Echtermeyer et al(2012) gave an outline on the underlying model and examination of a 4 10MW breeze turbine sharp edge. The underlying parts of a 70-rhythm long cutting edge in an upwind, vertical-pivot wind turbine were formed and make into utilization at high wind speed position. The construction of the cutting edge was make utilizing mutt blends which have glass and carbon fiber handles for yielding a featherlight plan with a low tip deviation. The sharp edge was subjected to FEA studies to show its capacity to repulse the outrageous replenishing conditions according to the transnational seaside wind standard. The outcomes checked the plan to have decent execution concerning tip deviation, outside and insignificant strains, and basic clasping freight.

Wenlei Sun etal.(2010) gave an outline on the plan and the investigation testing trouble in raising a largescale wind turbine sharp edge to work. Where the significant drawbacks are in the work enchant in the cutting edges plans on account of three-layered edges model.

Chalothorn Thumbhole and TawitChitsomboon et al(2006) suggested the meaning of ideal approach for untwisted cutting edge in wind turbine. Subsequently the mathematical reproduction of vertical hub wind turbines (HAWTs) with untwisted cutting edge was performed to decide the ideal approach that delivers the loftiest power undertaking. The mathematical outcome was done by working protection conditions in a turning reference outline wherein the sharp edges and lattices were fixed corresponding to the pivoting outline. Computational aftereffects of the 12 ° pitch contrast decidedly and the field exploratory information of The public Inexhaustible Research center (USA), for both inviscid and fierce circumstances. Mathematical preliminaries were directed by changing the pitch points and the breeze pets. The power works arrive at outside at pitch angles4.12 °,5.28 °,6.66 ° and8.76 ° for the breeze pets7.2,8.0,9.0 and10.5 m/s, freely. The ideal approaches were additionally accomplished from the information. Amano and Ryan Malloy et al (2013) made sense of about the improvement of cutting edge streamlined features and investigate the chance of adding the quantity of beneficial spots by enhancing wind turbine cutting edge plan for low wind speed regions.

Pedro Bañuelos-Sánchez etal.(2011) he gave an outline on low power-minimal expense vertical hub wind turbine for 350Watt activity. He depicts a plan and execution of a low power Level Pivot Wind Turbine where the hub of gyration is

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 346-353 www.ijaem.net ISSN: 2395-5252

resemblant to the ground. Rotor, edges, supporting mecca, and drive train are planned utilizing computational programming. authorized breeze turbine was tried and exploratory outcomes were accomplished for3.5 m/s to 9 m/s wind speed

II LITERATURE SURVEY

[1] Streamlined features OF WIND TURBINE

Wright and Wood et al (2004) noticed and made sense of about beginning a little level hub wind turbine at low wind speed they concentrated on conduct of sharp edges could produce surprising high force. Simultaneously, the non-layered pitch rate and diminished recurrence are excessively little to recommend a huge increment of the force through the impacts of insecurity. The force in this manner diminished attributable to improper edge approaches, which lead to a significant "inactive time" at both high and low wind speeds, in which the turning edges are sped up just leisurely and the approaches diminished gradually. Sikandar Khan et al. (2012) had a work on the streamlined investigation and dynamic displaying of little level hub wind turbine. This examination work, primarily center around powerful investigation and Pitch control of flat hub wind turbine. Pitch control is one of the most helpful and significant control, present in all of the ongoing breeze turbine models. For dynamic investigation and pitch control, reproduction procedures and test works were done one next to the other. Habali (2000) et al gave an outline of the activity of wind turbines at low profile in wind rates and he ready to find conceivable way through streamlined enhancement of the rotor edges, which is the main piece of a breeze turbine. Chen (2011) et al made trial study and he informed about the Streamlined shape improvement, which is one of the primary examination handles that is straightforwardly connected with power creation of a breeze turbine. The ideal conveyances of the harmony length and the contribute point each part can be gained by the plan boundaries, which incorporate the appraised breeze speed, number of edges, plan tip speed proportion and configuration approach. Arifujjaman et al (2008) demonstrated a little wind turbine with rolling component and researched the model bringing about elements. He mimics by managing the speed of the breeze turbine by means of a heap control technique. Tip speed proportion and slope climbing control techniques gives greatest power extraction from a little wind turbine. Limited scope wind 3 turbines introduced inside the constructed climate is named miniature age innovation. Ditkovich et al. (2014) had given an outline on a technique for assessing the fixed and variable speed turbine execution file. The methodology depends on Weibull wind likelihood conveyance capability and maker gave power bend. Xu et al. (2013) gave a concise report on building and made sense of about little wind turbine which got incredible consideration as of late for controlling low power gadgets with a physical science based thorough model for anticipating the exhibition of scaled down level pivot wind turbine. Dong alright Yu and Gracious Joon Kwon et al (2014) planned a little wind turbine generator framework which can be mounted in seaside regions and islands slop with a decent designs and a defensive framework for solid activity. A little wind turbine model with high unwavering quality is planned and analyzed in the genuine island conditions. Johansen et al (2002) made a concentrate on wind turbine sharp edges and he researched Streams close to edge tip and center point mathematically. He found the move through an untwisted edge HAWT is very convoluted to tackle mathematically due to the pivot of the turbine, combined with choppiness and slow down impacts, subsequently the turning wind turbine can be demonstrated with static or dynamic matrix technique.

[2) Streamlined Plan OF WIND TURBINE

Rotor plan, airfoil choice and Cutting edge plan comprise the streamlined plan of the cutting edge. Dynamic geste , strength and weakness packages of the rotor must be thought about when a breeze turbine is being planned and developed. The Rotor tip is planned with extraordinary consideration and flawlessness as the tip of the cutting edge moves principally quicker than the foundation of the edge. To choose the reasonable breeze turbine, three plan speed boundaries, videlicet cut-in wind speed Vcut in, evaluated breeze speed Vrated and cut out wind speed Vcutout can be determined by utilizing conditions. Grounded on the normal breeze pets in Tamil Nadu the rotor sharp edges are to be planned. In this investigation, the occasional typical breeze speed($\bar{u}$) of Tamil Nadu is expected to be 3m/s. The cut in speed is1.4 m/s and the cut-out speed is 9m/s for the typical breeze speed taken. This typical breeze speed is the appraised speed of the breeze turbine. 4. AIRFOIL Determination The fundamental motivation behind picking this airfoil when contrasted with different airfoils is to incite most extreme lift force by limiting drag force. This airfoil created compelling outcomes for wind turbines for various homegrown tasks. Lift force for the airfoil is high which is generally appropriate for low wind speed turbines. A high level L/D rate is additionally conceivable with non-balanced histories. This airfoil is picked on the grounds that it fulfills various of the plan standards for ideal breeze turbine rotor execution.

3) AIRFOIL Plan Approach

The course of airfoil configuration continues from an information on the limit subcaste bundles and the connection among figure and tension conveyance. The thing of an airfoil configuration fluctuates. A few airfoils are intended to create low drag(and may not be expected to incite lift by any means.) A few segments might have to deliver low drag while delivering a given quantum of lift. Now and again, the drag doesn't actually count it is greatest lift that is significant. The segment might be expected to accomplish this presentation with a requirement on consistence, or pitching second, or out-plan execution, or other strange imperatives. The overall consistence of air antipode shifts in the range course. For group, shape Max. Relative consistence, it diminishes from 40 of root to 10of brace peak, to acquire Max. Wind energy practicing measure. The styles for airfoil configuration can be characterized into two orders immediate and reverse plan.

4) DIRECT Plan framework

The immediate airfoil plan framework includes with particular of discrete airfoils which are figure segments, determined strain and execution. Utilizing the underneath boundaries or particulars of the airfoil, its hitherto will in general gauge the given shape and furthermore alters the shape to enhance the presentation. The two fundamental sub issues in direct arrangement of airfoil examination are

The distinguishing proof of the proportion of Execution

The way to deal with changing the shape so the presentation is bettered the least difficult type of direct airfoil configuration includes beginning with an expected airfoil shape (comparative as a NACA airfoil), deciding the particular of this segment that is most extreme issues some, and fixing this issue. The cycle includes fixing the most over the top deplorable Issues with a given airfoil and it's rehashed until no serious issue with the part is reasonable to set up. The plan of comparative airfoils doesn't bear a particular portrayal of a scalar ideal capability, yet it requires a spunk to recognize the verifiable issues and much of the time extensive pizazz to fix them.Due to the inconvenience and spunk inclusion, the current investigation work for airfoil configuration utilizes reverse plan of airfoils which is quibbled underneath.

Opposite Plan Framework

One more kind of goal capability is the objective tension dispersion. It's incidentally conceivable to indicate an asked Cp circulation and utilize the least places contrast between the real and focus on Cp's as the ideal. This is the basic thought behind various styles for reverse plan. As a representation, flimsy airfoil recommendation can be utilized to break for the state of the camber line that delivers a predetermined tension contrast on an airfoil in possibility inflow. The substitute piece of the plan issue begins when one has at any point characterized an ideal for the airfoil plan. This phase of the plan includes changing the airfoil shape to enhance the exhibition. This might be finished in more than one way

By hand Utilizing information on the products of figure changes on Cp and Cp changes on execution. By mathematical enhancement Utilizing shape capabilities to address the airfoil figure and allowing the PC to settle on the arrangement of varieties requested to improve the plan. The airfoils utilized in this investigation are Gottingen airfoils which havenon-layered direct enthusiasm length having profile consistence of unit length. Consequently, the airfoils are additionally measured to the enthusiasm length of the airfoil at each segment. Various airfoils are noted and tried for the breeze designs and the airfoil generally appropriate for the execution of the breeze turbine is named.

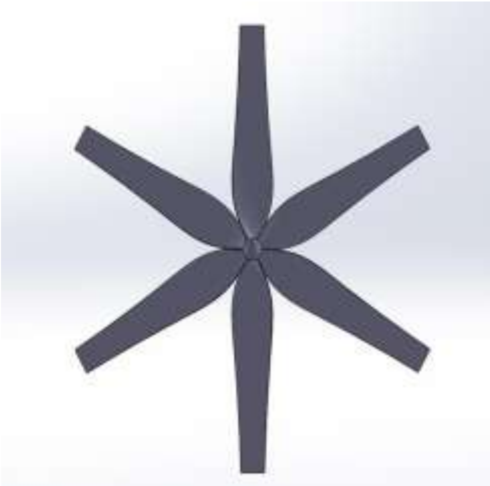
III METHODOLOGY

GOTTINGENPROFILES

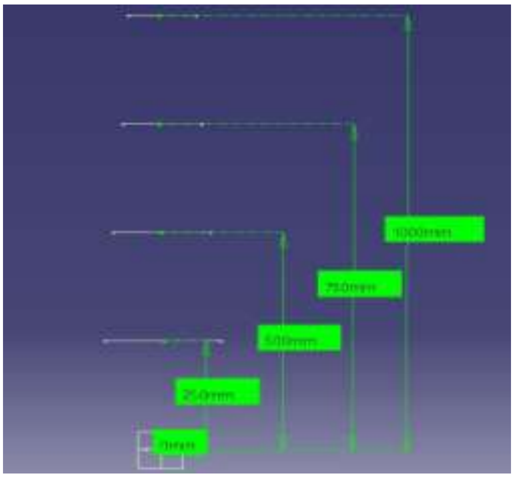
3.1 GOTTINGEN 364 AIRFOIL

Gottingen 364 is suggested for investigation. It has a maximum thickness of 10.8% and a maximum camber of 6.5% at 30% chord. Table 3.2 shows the non-dimensional linear chord length and profile thickness of Gottingen 364. This is an asymmetric profile, and depending on the profile, the thickness of the profile on either side of the mean line may vary.

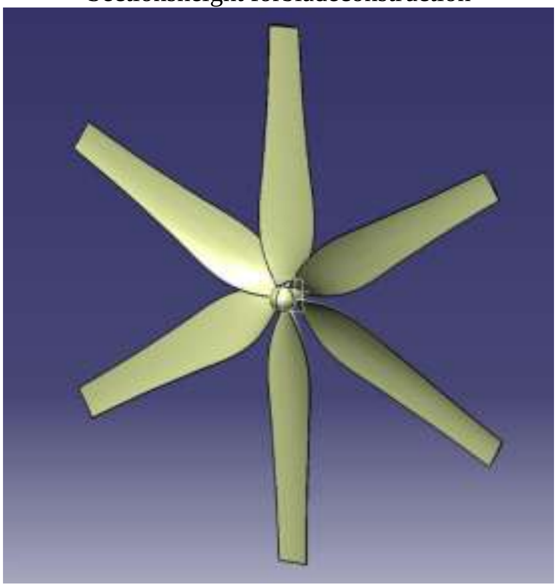
BladeProfileGottingen364



BladeFront View

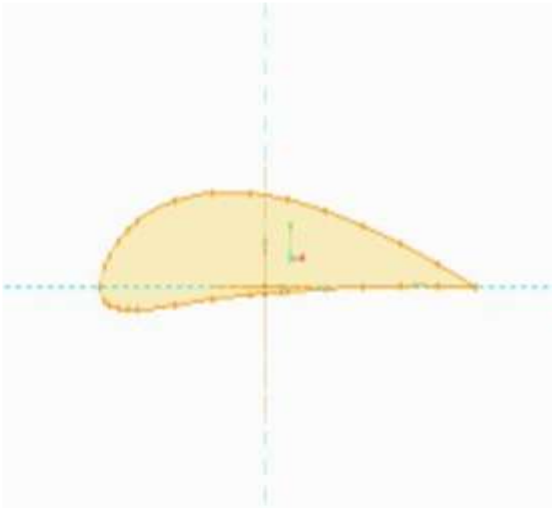


Sectionsheight forbladeconstruction

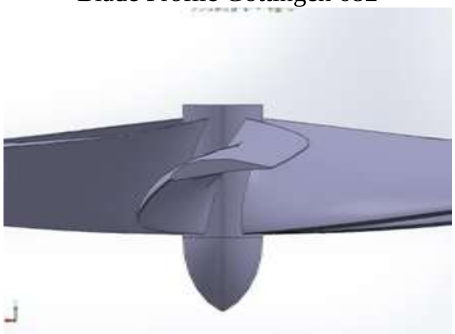


Final Blade (Surface Model) according to sections

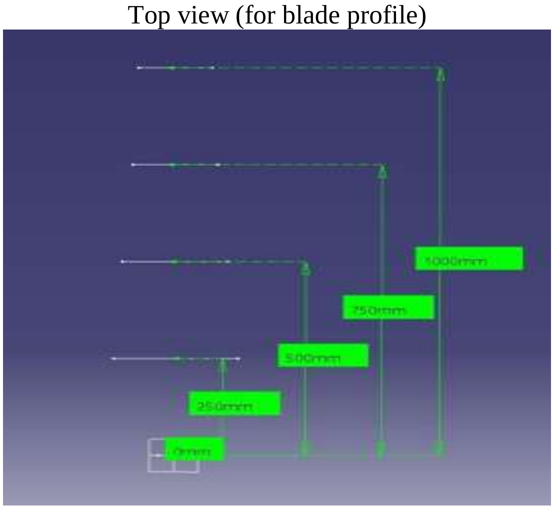
3.2 GOTTINGEN 682:-Gottingen 682 is proposed for examination. At 30% chord, it has a maximum thickness of 10.7% and a maximum camber of 4.3%. Gottingen 682's non-dimensional linear chord length and profile thickness are shown in the table. This is an asymmetric profile, and the thickness of the profile on either side of the mean line may vary depending on the profile.



Blade Profile Gottingen 682

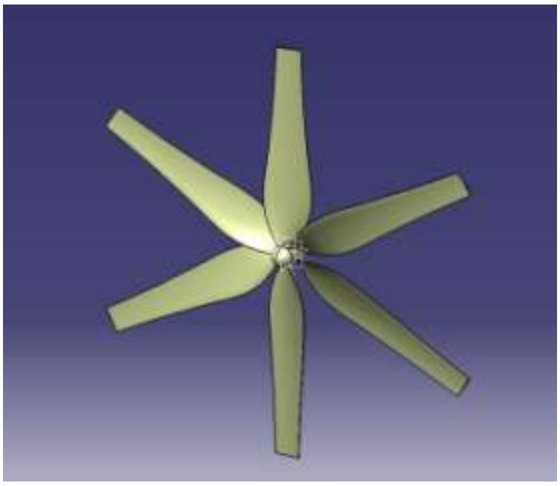


Top view (for blade profile)



Sections height for blade construction

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 346-353 www.ijaem.net ISSN: 2395-5252



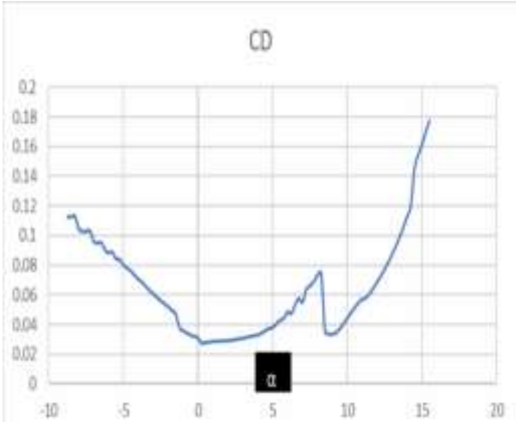
final blade (surface model according to sections)

3.3.1 NUMERICAL ANALYSIS
The displayed sharp edge is saved in the (STEP) design.
• This model is brought into ANSYS 2020R1 work seat in the Familiar solver.
• In the plan modeler of the ANSYS the liquid circle is demonstrated with a straight line, MRF zone and the power source pipe.
• The cutting edge is kept in the MRF zone. This is additionally brought into the cross-section module of the examination programming.
• A fix adjusting network is finished.
• The lattice is currently imported to the familiar solver and the fundamental limit conditions are characterized.
• The reenactment is run till conjunction of the response. The outcomes achieved are plotted and contrasted and the hypothetical outcomes.
. Examination System
construction of sharp edges
• For displaying the turbine, we first choose the airfoil area. Grounded on the data from the sharp edge development table, the airfoil segments of brilliant enthusiasm lengths are place at explicit segments in the sharp edge.
• The airfoil focuses are imported in to the modeler and a face is made as displayed in Figure along the beautiful airfoil segments as displayed in Figure.

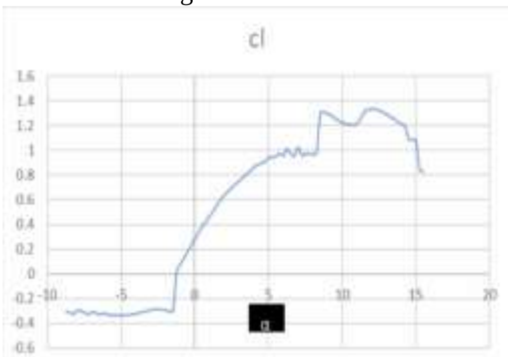
IV RESULT

The mathematical outcomes for the different airfoils for the given edge are talked about. This section additionally shows the presentation of the airfoils. After the arrangement has been merged, the CFD post handling strategy is utilized to get the different outcomes, which are shown as diagrams and shapes. The investigation yielded the accompanying outcomes:
• Coefficient of lift • Coefficient of drag
• Smoothes out
• Pressure shape
• Speed form

4.1 WIND TURBINE ROTOR GOE-364



The above graph shown represents CD vs α (Angle of attack) maximum CD of the airfoil reaches at 15 Degree of of attack.



The above graph shown represents Cl vs α (Angle of attack) maximum Cl of theairfoilreachesat9Degreeof AngleofattackandClvalueis1.3respectively

COMPUTATIONAL Aftereffects OF WIND TURBINE

An outline of the computational outcomes embraced in this disquisition is introduced in this part. The CFD assessments redounded in a few captivating compliances. The figure demonstrates the typical scramble of the breeze raising a ruckus around town edge at the evaluated speed of the turbine. Figure9.33 Dispersion of Shape of scramble over the cutting edge as the outcome the flurry greatness has a most extreme worth at the tip of the edges and is basically zero at the focal point of the mecca. The very truth is that all the edge tips show greatest scurry and this guarantees that the turbine's hub goes through the focal point of the mecca and is adjusted properly without upsetting the openness of the turbine. This disquisition additionally presumes that the turbine is turning in theanti-clockwise bearing. Examination on figure of strain uncovers that the tension is employed on the breeze turbine sharp edges by the approaching air.As found in the tension figure on the cutting-edge face is in the scope of 100 Dad and the perception shows that the hazier district is where the strain is high and that it's pivoting in theanti-clockwise heading. These tension plots don't influence the computational power issue adversely in light of the fact that they do at the inward edge length, which contributes essentially nothing to the accessory in the edges. The scurry extent figure uncovers the way of the breeze when it raises a ruckus around town and goes through the turbine at a consistent state. The way of the breeze would fluctuate at each second for a blaze state investigation. The smoothes out educate us regarding the way of the breeze as it raises a ruckus around town. This way differs consistently. The smoothes out of air go through the breeze turbine. We can see that the breeze inflow is concentrated towards the mecca. As the turbine is pivoting, the air before it's smelled in and pushed out. This will sire a tension drop before the turbine. The sharp edge point is set so that the beginning neckband is high. The smooth out of air goes through the turbine edges as displayed in Figure. The mathematical outcome, for the flurry at evaluated power is near the trial values. The high edge point at the root gives high beginning accessory to the low wind pets. From the smooth out disquisition, obviously the breeze speed standards around3.4 m/s. After the outcome is assembled, the CFD present handling is run on gain the brilliant outcome.

V CONCLUSION

Under regular plan conditions, the appraised force of 1kW was accomplished by vigilant preliminary and was sufficiently approved with the assessments on CFD. The experimental outcomes demonstrate that the cutting edges were adequately viable and it followed the plan contemplations of the turbine. The breeze refuge tests were valuable to choose the edge points by showing the pace of lift to drag segments at various areas along the length of the sharp edge. The cutting-edge plan and the presentation of these cutting edges in low wind speed conditions were seen at 300 rpm and reproduction results protect ideal power undertaking at3.4 m/s. It was seen and exhibited that the edges were planned effectively and the evaluated power issue was accomplished at a genuinely low wind speed of4.4 m/s.

REFERANCE

[1]. Arici, O, Chang, YL & Yang, SL 1995, ‘Navier-Stokes Computations of the NREL Airfoil Using K-w Turbulent Model High Angles of Attack’. Journal of Solar Energy Engineering, vol. 117.

[2]. Arifujjaman, MD, Iqbal, MT &Quaicoe, JE 2008, ‘Energy capture by a small wind-energy conversion system’, Applied Energy, vol. 85, no. 1, pp. 41-51.

[3]. Ashuri, T, Zaaijer, MB, Martins, JRRA, Zhang, J 2016, ‘Multidisciplinary design optimization of large wind turbines – technical, economic, and design challenges’, Energy Convers Manage vol. 123, pp. 56–70.

[4]. Bahaj, AS, Meyers, L, James, PAB 2007, ‘Urban energy generation: influence of micro- wind turbine output on electricity consumptions in buildings’, Energy and Buildings, vol. 39, no. 2, pp. 154e165

[5]. Bahaj, AS, Myers, L & James, PAB 2007, ‘Urban energy generation: Influence of micro-wind turbine output on electricity consumption in buildings’, Energy and Buildings, vol. 39, no. 2, pp. 154-165.

[6]. Bai, CJ, Hsiao, FB, Li, MH, Huang, GY & Chen, YJ 2013, ‘Design of 10 kW Horizontal- Axis Wind Turbine (HAWT) Blade and Aerodynamic Investigation Using Numerical Simulation’, Procedia Engineering, vol. 67, pp. 279 – 287.

[7]. Barnes & Morozov, EV 2016, ‘Structural optimization of composite wind turbine blade structures with variations of internal geometry configuration’, Journal of Composite Structures, vol. 152, pp. 158-167.

[8]. Bastankhah, M & Porte-Agel, F 2014, ‘A new analytical model for wind-turbine wakes’, Renewable Energy, vol. 70, pp. 116 - 123.

[9]. Bazile’s, Y, Hsu, MC, Ackerman, I, Wright, S, Takizawa, K, Heinicke, B, Spielman, T &Tezduyar, TE 2011, ‘3D simulation of wind turbine rotors at full scale. Part I: Geometry modeling and aerodynamics’, International Journal for Numerical Methods in Fluids, vol. 65, pp. 207-235, 2011.

[10]. Bottasso, CL, Campagnolo, F, Croce, A, Dilli, S, Gualdoni, F & Nielsen, MB 2013, ‘Structural optimization of wind turbine rotor blades by multilevel sectional/multibody/3D-FEM analysis’, Journal of Multibody Syst Dyn., pp. 1-30.

[11]. Braslow, AL 1999, 'A History of Suction-Type LaminarFlow Control with Emphasis on Flight Research', NASA History Division.

[12]. Brian Hayman 2007, 'Approaches to Damage Assessment and Damage Tolerance for FRP Sandwich Structures', Journal of Sandwich Structures and Materials, vol. 9, pp. 571- 596.

[13]. Brown, KA & Brooks, RA 2010, 'Design and analysis of vertical axis thermoplastic composite wind turbine blade', Journal of Design and analysis of wind turbine blade, vol. 39, no. 3-5, pp. 111-121.

[14]. Cairns, DS & Mandell, J 2000, 'Design Considerations for Buckling in Composite Wind Turbine Blades', AIAA-2000-59, 38th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan. 10-13.

[15]. Castelli, MR &Benini, E 2011, 'Effect of blade inclination angle on a Darrieus wind turbine', Journal of Turbomach., vol. 133. 16. Castelli, MR, Englaro, A &Benini, E 2011, 'The Darrieus wind turbine: proposal for a new performance prediction model based on CFD', Energy, vol. 36, no. 6, pp. 4919e4934.