International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Design and Fabrication of Small Horizontal axis wind Turbine Rotors at Low Reynolds Number

Manoj Kumar Chaudhary, S. Prakash

***Abstract:** This research paper presents a design and fabrication of 100 Watt small horizontal axis wind turbine with 0.24 m and 0.35 m rotor radius and tip speed ratio varies from 2 to 10 was designed and development for operated at low wind speed with Low Reynolds number. In this paper, a new airfoil profile was designed and developed, it's denoted by MK115. The numerical and experimental analysis for 6 airfoils using Xfoil software was conducted with a view to evaluating the lift-to-drag ratio and angle of attack by means of the SD7024, SG6043, NACA2412, S1210, E213, and New Airfoil (MK115) tested. In simulation, new MK115 airfoil was the most convenient airfoil to start high energy production for low-wind applications, on the Reynolds number 25000, 50000, 75000, and 100000 in improved airfoil (MK115) tests an Open type wind tunnel. An Xfoil analysis to obtain further data on the flow characteristics was also conducted. (MK115) airfoil have C_{Lmax} of 0.92, 1.25, 1.69, 1.67 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0 .A maximum lift to drag ratio (Cl/Cd) of 7,16,50,63 at Re=25k, 50k, 75k and 100k for New airfoil (MK115) at angle of attack (α) =4^0, 4^0, 8^0, 8^0. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.37, 0.36, 0.4, 0.39, 0.44, and 0.44 at tip speed ratio (λ) =6 for Reynolds number is equal to 100000. MK115, Maximum Torque obtained 0.9744 Nm, 1.389 Nm and 2.4866 Nm at blade angle =0, 15 and 30 degrees respectively. Power coefficient (Cp) =0.51, 0.5, 0.46, and 0.4 at Rotor shaft angle=0^0, 5^0, 10^0, and 15^0 respectively for the new airfoil results.*

Keywords: Small Wind Turbine; BEM; X-foil; Airfoil; Blade Angle; Power coefficient; Reynolds number.

I. INTRODUCTION

A. Small horizontal axis wind turbines

The heart of any renewable wind power generation system is the Wind Turbine. Wind turbine designs on the other hand use the force of the wind to generate electricity. The winds movement spins or rotates the turbines blades, which captures the kinetic energy of the wind and convert this energy into a rotary motion via a shaft to drive a generator and make electricity as shown .Small wind turbine is a wind generator used for micro generation with higher personal energy production. The design and analysis of 2kw small horizontal axis wind turbine used for low Reynolds number applications. Electricity supply from unused energy can be supplied via the electricity grid with slightly bigger turbines for contributing to a national supply. Small wind turbines achieve power coefficients of 0.25 or greater in comparison to large turbines which have C_P values around 0.45 **[1]**

B. Small wind turbine at low wind speed

The micro wind turbine unit that was designed project has 500 mm blade diameter and 4.8 kg weight.

It was confirmed that µF500 shows a good efficiency in the wind range of 8m/s to 12 m/s. The maximum power coefficient was about 0.40 when the tip speed ratio was 2.7 **[2].**

C. Changing of the airfoil section for small wind turbine blade

The aerodynamic designed of using NACA-4420 airfoil. They discover that HAWT effectiveness relies heavily on the profile of the blade and its orientation **[3]**.. Turbine blade design has been designed using S822 airfoils and the blade aspect ratio is 8.02 split into 3 m radius and 0.374 m chord width. The aerodynamic curves of the lift and drag coefficients with the S809 airfoil between the angles of attack 30 ° and 90 ° at different amounts of Reynolds were defined as mathematical models to be simply combined with the S809 airfoil **[4]**.

D. Effect of drag force and lift force

A mathematical template; the appropriate layout for quickly operating wind turbine engines was acquired by using blade element theory and momentum analysis to calculate the region below the curve (C_P-λ). The study concluded that C_P maximum value is only 0.47, reached at a top speed ratio of 7, **[5]**. Experimental lift distribution results have shown that the values C_l for Re = 38000 ranged between 0.41 and 1.05 at the angle attack = 18° for Re = 75,000, 128,000 and 205,000, Clmax = 1.7, 2, 1.81 and 1.86 at the angle of attachment of 14^o, respectively **[6].**

E. Small wind turbine rotor blades

Small wind turbines suffer from a large resistant torque caused by friction in connection with transmission gearboxes, rotor coils and generators which must be overcome before rotation begins **[7]**. Aerodynamic optimization of the rotor blades must achieve elevated efficiency benefits from the wind. The optimization of the chord and spin allocation, amount of blades, airfoil design and the velocity ratio.**[8].** The energy ratio (C_p) for the chosen airfoils was diverse with regard to Tip Speed Ratio (k).From the simulation outcomes, an optimal energy coefficient was found for the C_P SD7081, for the Reynolds (Re)= 81712, with the SD7080 airfoil tip= 0,34 at λ= 6. In contrast with λ and energy coefficient the SD7080 airfoil blade was evaluated for various Re scores (30642, 40856, 51070, 61284, 71498 and 81712), at a low Re=40856 at λ=5–6, the highest energy ratio was 0.29**[9]**. The Results show that wind energy is enhanced because of the rise in the air speed that affects the blade of the wind turbine. The wind power increases slightly for the shift of blade angle from 20^o to 60^0 and maximizes if the blade angle is equivalent to 90^0 **[10]**.

Revised Manuscript Received on October 30, 2019.
***** Correspondence Author

Manoj Kumar Chaudhary*, Assistant Professor of Mechanical engineering at the Dr. D. Y. Patil School of Engineering, Pune (India).

Prakash Subramanian, Professor and Dean in the School of Mechanical Engineering, Sathyabama University, India,

The fresh airfoil geometry and wind turbine blade approach was implemented Small changes on small wind turbine blades operating at less than 500,000 Reynolds, blade parameters such as pitch angle, chord and twist distribution were also discussed .The 4D printing method has proved a fresh paradigm for the design and manufacture of wind turbine blades. **[11-12].** Airfoil SG 6043 has been chosen in their research. Their experiments for varying chord and bent blade with solids ranging from 2% to 30% and blade numbers 3, 5, 7, 12 and 15 with rotor diameter of 2 m were performed **[13].**The wind turbine generated, on average, a power coefficient (Cp) of 0.255 (8,22 m) at a wind speed of 6 m / s (18° pitch) by The maximum C_p based on 10 s information was 0.291 with the free stream speed of 6 m / s **[14].** This article provides the design and efficiency outcomes of a small wind turbine with a 100 W horizontal axis with a 0.48 and 0.70 diameter, 3-bladed and 5-bladed respectively rotor intended for low-Reynolds number implementations with a wind speed of 2 to 8 m / s. The present work studies and experimental investigation of various airfoils at low Reynolds number, at different angles of attack and tip speed ratio. The main aim of this research work is to developed new airfoils which are operated at low wind speed of horizontal axis wind turbine blades. In the present work, design, Aerodynamic parameters Investigation and fabricated of 6 airfoils was carried out at Reynolds number of 25000, 50000, 75000 and 100000 using X-foil software and new airfoil develop.

II. METHODOLOGY:

The blade and hub designed and optimized in Q Blade software. Blades and hub material selection was done in Cura software, further blades and hub fabricated by 3D printer using ABS and PLA materials. The blades were designed and optimized for the selected airfoils based on Blade Element Momentum theory with consideration of Tip losses, Wake Losses and Prandtl's losses. Optimized rotors were tested in wind tunnel by varying the shaft angle.

Table I: Details of selected airfoil

Sr. No.	Airfoil	Thickness (%)	At (%)	Camber (%)	at (%)
1	E214	11.1	33	4.03	52
2	SG 6043	10.02	32.1	5.5	49.7
3	NACA 2412	12	30	2	40
4	S 1210	12	21.51	7.2	51.11
5	SD 7034	10.51	26.05	3.89	39.4
6	**MK 115**	**11.19**	**24.9**	**5.88**	**51.3**

Table II: Selected & New Airfoil (MK115) Performance

Sr. No.	Airfoil Type	Max Camber	Max. lift Coefficient	Max. L/D Ratio
1	**MK 115**	**5.88 % at 51.3 % chord**	**1.45**	**64**
2	NACA 2412	2 % at 39.5 % chord	0.88	50
3	SG 6043	5.1% at 53.3% chord	1.27	59

The new airfoil was developed based on existing low Reynolds number airfoil investigated through Xfoil software and experimentation tested in wind tunnel, a new airfoil name was given by MK 115, its details and specification are shown in Table 1. The new airfoil is fabricated by 3D printer and tested in open type wind tunnel at different blade angle and different wind velocity.

A. Selection and optimization of a low Reynolds number airfoil through x-foil

In this study and experimental investigation, of 05 airfoils viz. E214 (11.1%), SG 6043 (10.02%), NACA 2412 (12%) S 1210 (12%) and SD 7034 (10.51%), by using Xfoil software we have analysis different airfoils by putting in it shows in Fig. 1. Its functionality allows the user to rapidly design custom airfoils and compute their performance polar and directly integrate them into a wind turbine rotor design and simulation. The software is especially used for design and simulation capabilities for HAWT rotor design and shows all the fundamental relationships of design concepts and turbine performance in an easy and intuitive way. From the simulated results, the best blade geometry was selected and analyzed for different Reynolds number; try to developed new airfoil and small wind turbine rotors, which are feasible for low wind speed region.

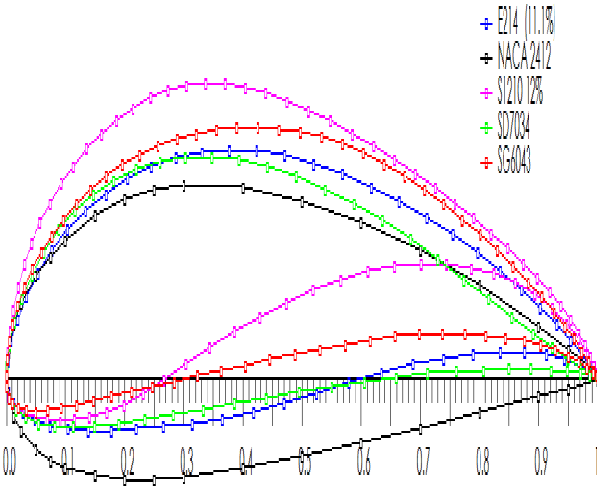

Fig. 1. 2D diagrams of different airfoil in Xfoil

III. ROTOR BLADE DESIGN METHODOLOGY

For the best small wind turbine blades the various parameters like, tip speed ratios, blade angle, blade geometry are studied and optimized in present work, the blade geometry optimized in Matlab software with more than 100 iterations. The best airfoil and new airfoil was selected and developed by using X-foil software. The blade material selection and machine parameters was optimized in cura software, the blades are manufactured by 3D printer. Finally optimized blade airfoil and rotors are investigated in open wind tunnel at different wind speed and blade angles. A wind turbine extracts the kinetic energy from the wind by slowing down the wind, so it is essential that this energy is transferred to the wind shaft so that it is well designed. The accessible wind power for processing is dependent on both the wind speed and the region of the turbine blades. We can say that the manufacturing of wind turbines depends on how the rotor blades interact with the wind and that this relationship is essential for the layout of the wind turbine.

A. Blade Element Momentum Theory

The analysis here uses momentum theory and blade element theory. Momentum theory refers to a control volume analysis of the forces at the blade based on the conservation of linear and angular momentum. Blade element theory refers to an analysis of forces at a section of the blade, as a function of blade geometry. The results of these approaches can be combined into what is known as strip theory or blade element momentum (BEM) theory. This theory can be used to relate blade shape to the rotor's ability to extract power from the wind.

IV. ANALYTICAL MODEL SIMULATION

The main purpose of this study is to design investigation and develop new airfoil for small wind turbine blades for operation in low wind speed regime. Aerodynamic optimization of the small wind turbine blade is determined by proper choice of Airfoil shape, angles of attack, blade angle, tip speed ratio, blade geometry, Reynolds number and pressure coefficient. In order to determine the optimum distribution of chord and twist along the length of the blade, a Blade Element Momentum (BEM) based program was developed in MATLAB. The ultimate objective was to minimize the cut-in wind speed. A simulation based design and optimization process was adopted. The limit of different parameters within which the design was sought is shown in Tables (I-IV). Laminar flow is expected for Airfoils at low Reynolds number 25000, 50000, 75000 and 100000 Reynold numbers is used for this analysis and investigation for various airfoil at angle of attack 2 degrees to 10 degress. Operating point view visualizes the boundary layer and pressure produced on new airfoil at an angles of attack 2, 4, 6, 8 and 10 degrees.

Table III: Rotor Specification

Sr. No.	Airfoil	Blade Radius (m)	Max Cp (Xfoil)	Optimized TSR	Hub Radius (m)
1	MK 115	0.24	0.51	6	`0.01
2	NACA 2412	0.35	0.44	6	0.02
3	SG 6043	0.35	0.53	6	0.02

Table IV: The Chord and Twist angle distribution for various sections of different airfoils

Sr. No.	**Rotors Type**	**Airfoil**	**Chord Length (m)**		**Twist Angle (˚)**	
			Root	**Tip**	**At Root**	**At Tip**
1	**R1**	**MK115**	**0.0255**	**0.0182**	**10**	**1.25**
2	R2	NACA 2412	0.026	0.015	27.5	1.25
3	R3	SG 6043	0.026	0.015	27.5	1.25

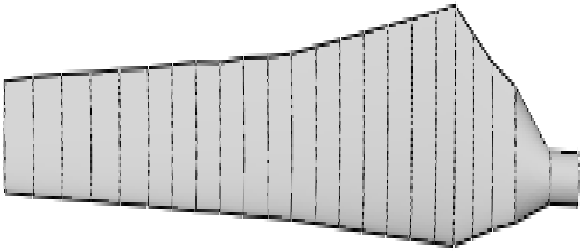

Fig. 2. Optimized Blade model for new airfoil (MK 115)

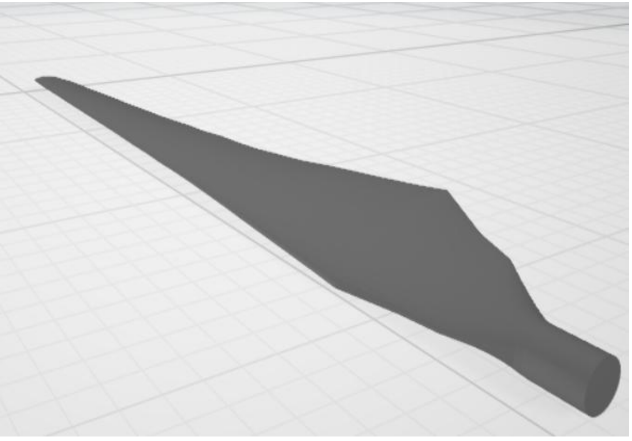

Fig. 3. Optimized Blade model for NACA2412 airfoil

Fig. 4. Optimized Blade model for SG6043 airfoil

For improved performance of the wind turbine at lower wind speeds, it is necessary that the chord length is larger at the inner sections of the blade (closer to the root) and smaller at the outer sections of the blade [8].The tip section angle are set to high twist angle & the root section to less twist angle, which contributes rotors work at low wind regime. The various rotor blade model of simulation and prepared 3D model for fabrication are shown in Figure 2 to 4.

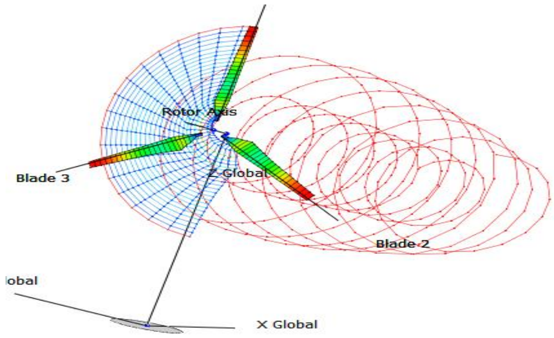

Fig. 5. Rotor simulation of wake effects for Single blade

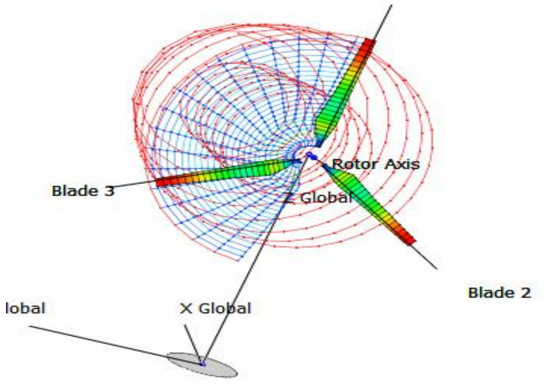

Fig. 6. Rotor simulation of ake effects for three blades

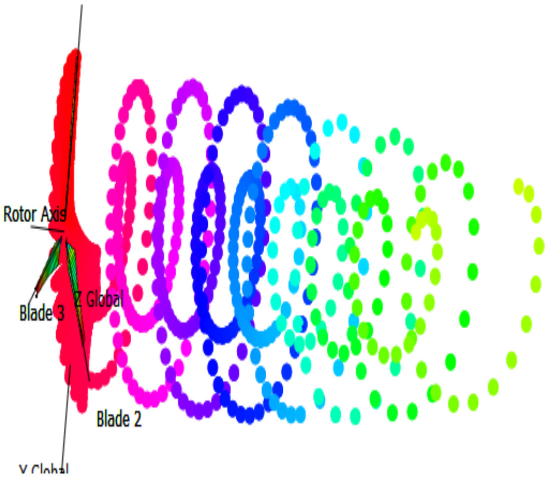

Fig. 7. Vortex Simulation Results from Q-Blade Software for single blade

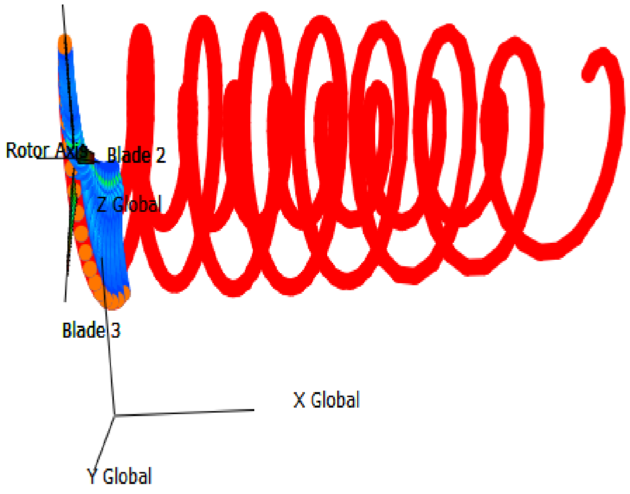

Fig. 8. Vortex Simulation Results from Q-Blade Software Rotor wake

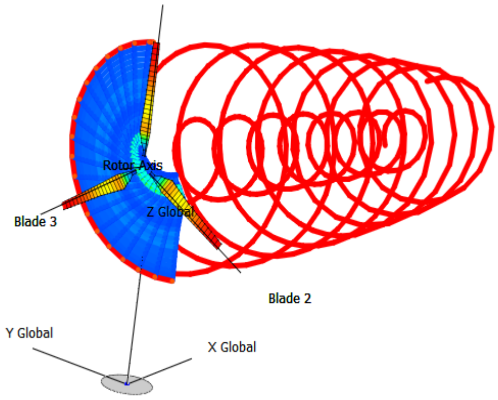

Fig. 9. Vortex Simulation Results from Q-Blade Software Rotor wake

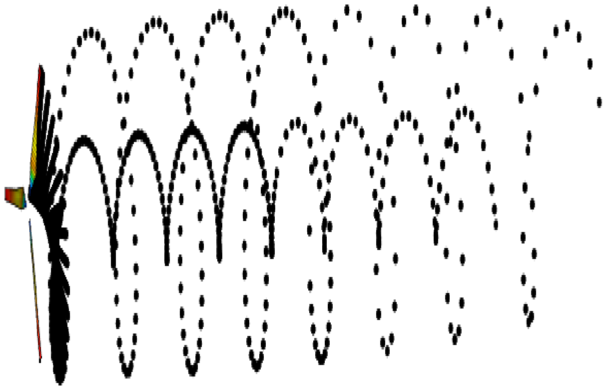

Fig. 10. Vortex Simulation Results from Q-Blade Software for new airfoil Vortex Elements 3921)

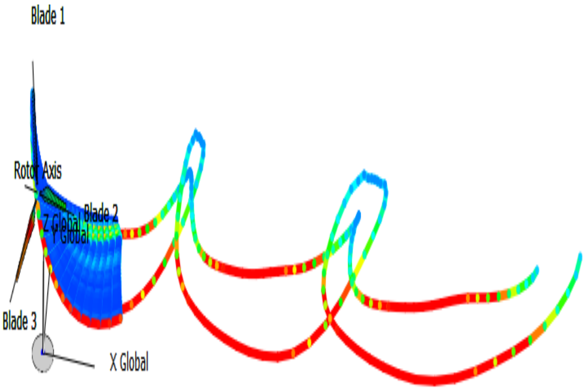

Fig. 11. Trailing vortices of SG 6043 Airfoil 0 degree Blade angle for Single Blade.

A numerical analysis was performed Fig-5 to Fig. 12 is showing the various Power coefficient curve, blade model, Vorticity curve, wake effect on rotor performance behind blades of 3 blade and 5 blade wind turbine, different shaft angle, Winfield simulation and airfoil analyzed for understanding purpose

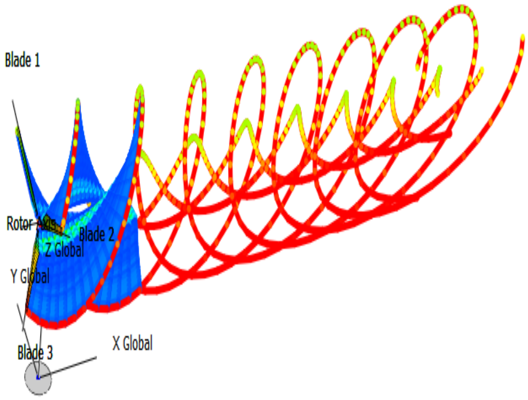

Fig. 12. Trailing vortices of SG 6043 Airfoil at different Blade angle three blades at 20 degree

From Fig 5 & 6 wake impact on blade efficiency can be noted, but wake impact also rises behind the rotors when the size and blade quantity rise. Figure 7 to 10 demonstrates the design of the Vortex simulation also relies on the design of the airfoil and blade. The power coefficient as a function of tip speed ratio as shown in Fig 11 to 12, depicts the response of Blade element momentum theory blades at Re=100000 for new airfoil developed for low Reynolds number. Fig.11 to 15 shows the rotors performances by variations of different shaft angle with respect to Reynolds number for new airfoil simulation. Fig 10 to 12 shows the FEM simulation, Vortex Simulation, Wake effect, Trailing Vortices for SG 6043, NACA 2412 and New Airfoil of the wind turbine blade at different blade angles compared to each other. Fig 12 shows the Blade model obtained from Q-Blade software SG 6043 Airfoil for 3 Blade rotors , SG 6043 Airfoil for 5 Blade rotors and NACA 2412 Airfoil for 3 Blade rotors at Re= 25000, 50000, 75000 and 100000, Result graphs indicates the Winfield Simulation from Q-Blade results of different rotor radius. Fig.4. Shows three view for three dimensional wind turbine blade profile in Cura software at 0% filled, 50% filled and 100% filled condition. Fig. 13 to 15 shows three views for three dimensional wind turbine blade profiles, materials selected were ABS and PLA for wind turbine blades and rotor hub respectively.

Fig. 13. Manufactured components in 3D Printer

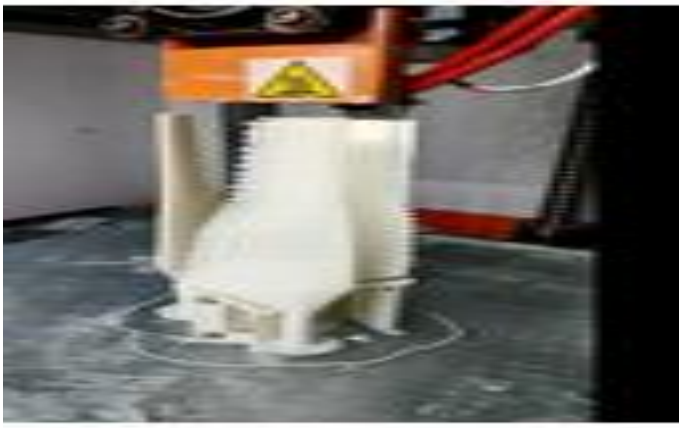

Fig. 14. Manufactured components in 3D Printer for blades

Retrieval Number: L34991081219/2019©BEIESP
DOI: 10.35940/ijitee.L3499.1081219
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Fig. 15. Optimized Blade & Hub Manufactured by 3D Printer (a) Blade=3, MK115 airfoil (b) Blade=3, Naca 2412 (c) Blade=5, SG 6043 airfoil

Fig. 15 (a, b, c) shows the fabrication of the wind turbine blade by 3D printer. Fabrication of the entire wind turbine blades and hub model is made using ABS material. ABS is a powerful, highly durable and chemically resistant thermoplastic by itself. ABS capped acrylic, more commonly referred to as acrylic capped ABS, is a combined thermoplastic designed to exhibit the best ABS sheet and acrylic sheet properties to make a reliable, attractive and mouldable plastic.Fig. 15 shows the optimized blade geometry of fabricated blade for New airfoil(MK 115), NACA 2412 and SG 6043 for 24 cm, 35 cm and 35 cm length of blades respectively at Reynolds number is equal to 100000. The unwanted areas were removed using grinding machines. Fine and smooth finshing to the blades were given by filling the surfaces.

V. EXPERIMENTAL AND NUMERICAL PROCEDURES

Experimental work was conducted in the open wind tunnel at Dr. D. Y. Patil School of Engineering, Lohegaon Pune. Air is blown or sucked through a duct equipped with a viewing port and instrumentation where models or geometrical shapes are mounted for study. Typically the air is moved through the tunnel using a series of fans. This tunnel consists of centrifugal fan, diffuser, duct, air box, holder, and nozzle. The motor of the centrifugal fan is three-Phase AC motor with power factor equals 0.87 and rotational speed 1460 rpm with rated power of 40 hp. The nozzle exit cross-section is 100cm x 100cm and its center is above the ground by 134 cm. The wind turbine blades are attached to the hub and this rotor-hub assembly is kept in front of nozzle

Fig. 16. Wind tunnel setup

Fig. 17. Blade tested in wind tunnel

Fig.16-17 shows the wind tunnel experiments of small wind turbine rotors. The experiments were performed under Department of Mechanical Engineering, in Fluid mechanics lab. open circuit wind tunnel in Fluid mechanics laboratory of Ajinkya D. Y patil University, Lohegaon, Pune (Maharashtra) (Dr, D, Y, Patil School of Engineering under pune university). The 3-Bladed and 5-Bladed wind turbine model with different airfoil was tested at different wind speeds and different rotor angle. Fig. 17 shows the free rotor rpm readings were taken by hand held laser tachometer at root and tip of the blade. Fig. 17 shows the wind velocities reading were taken by digital anenonometer at outlet of the wind tunnel. Wind velocity controller, to control wind velocity inside the wind tunnel. The mostly small wind turbine operating range was to be 3 to 8 m / s. Due to an aero elastic phenomenon, when the wind speed was raised beyond 9 m / s, vibration was sensed during the experiment. Therefore, wind turbine was not evaluated in excess of 8 m / s. The wind turbine's tip velocity ratio was discovered to rise with increased wind speed. Between 7 and 8 m / s wind rates,

VI. RESULTS AND DISCUSSION

This chapter represents the different graph made for different parameters. A main consideration in obtaining accurate projections of a specified wind turbine output by BEM techniques and wind tunnel texting is to use the polar airfoils at small Reynolds numbers equivalent to the turbine's working circumstances

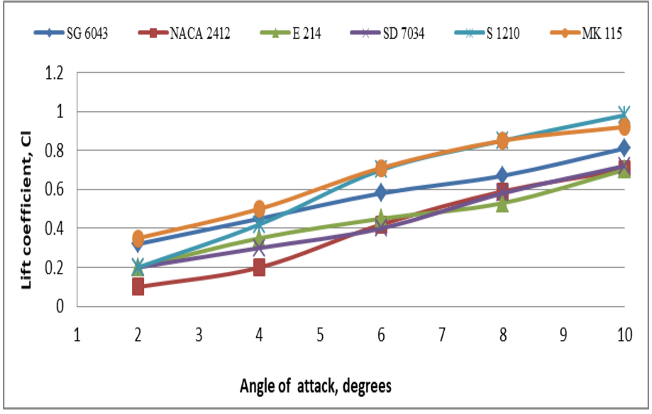

Fig. 18. Variations of lift coefficients of different airfoils suited for small wind turbines at Re =25000

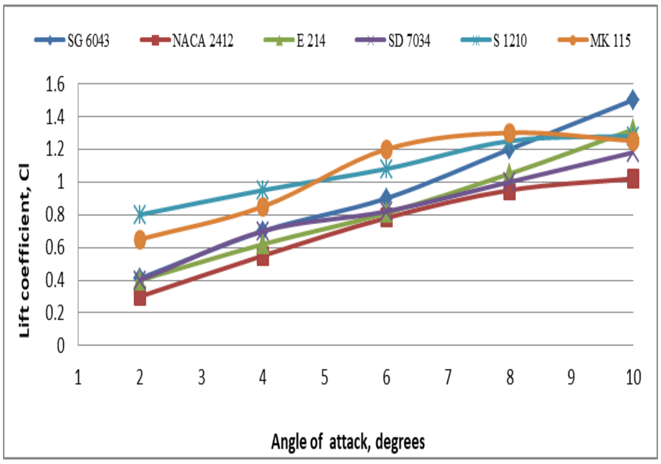

Fig. 19. Variations of lift coefficients of different airfoils suited for small wind turbines at Re =50000

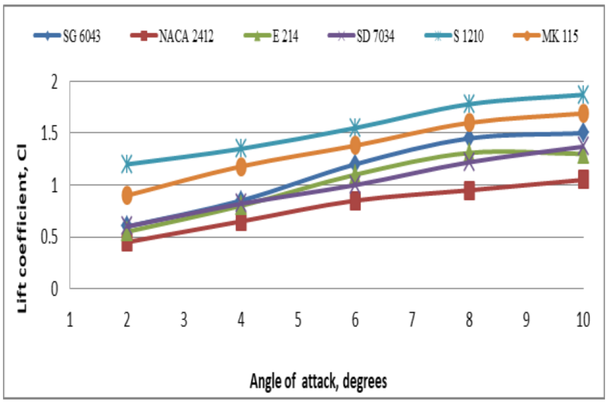

Fig. 20. Variations of lift coefficients of different airfoils suited for small wind turbines at Re =75000

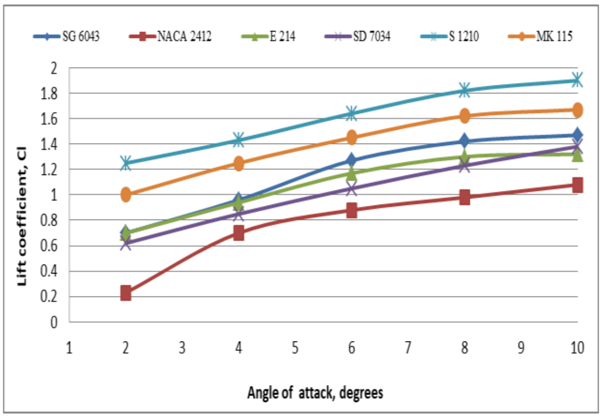

Fig. 21. Variations of lift coefficients of different airfoils suited for small wind turbines at Re =100000

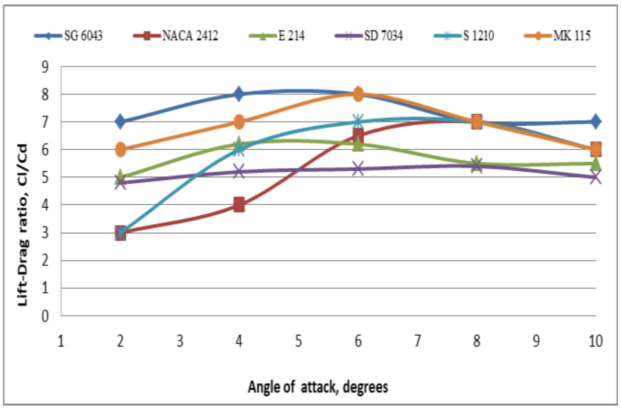

Fig. 22. Variations of lift-Drag ratios of different airfoils suited for small wind turbines at Re =25000

Given this reality, Reynolds numbers were calculated for each of the wind rates regarded at the airfoils place along the blade range using the rotor's design tip speed ratio of 5 to 7. In XFOIL, the polar airfoils were calculated in a spectrum of corners of assault from 5 to 10 degrees. Fig. 18-21 shows the variation of lift coefficient (CL) with respect to different angles of attack for the selected and new airfoils such as SG 6043, NACA 2412, E214, SD7037, S1210 and New airfoil (MK115) at Re=25000, 50000,75000 and 100000. From Fig 18-21 it was observed that the lift coefficient values are strongly influenced by the angle of attack (α).From the graph it can be detected that, SG6043, S1210 and New Airfoil (MK115) airfoil produces CLmax of 0.8 to 1.2 at angle of attack from 7 to 10 degrees.

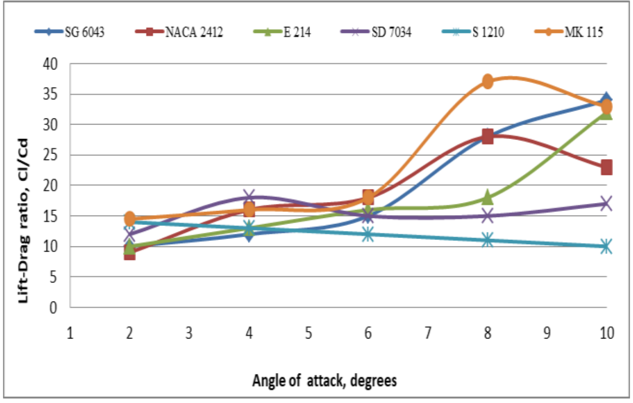

Fig. 23. . Variations of lift-Drag ratios of different airfoils suited for small wind turbines at Re =50000

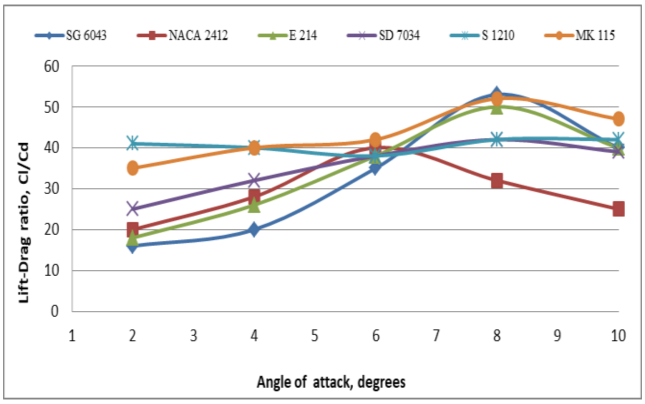

Fig. 24. Variations of lift-Drag ratios of different airfoils suited for small wind turbines at Re =75000

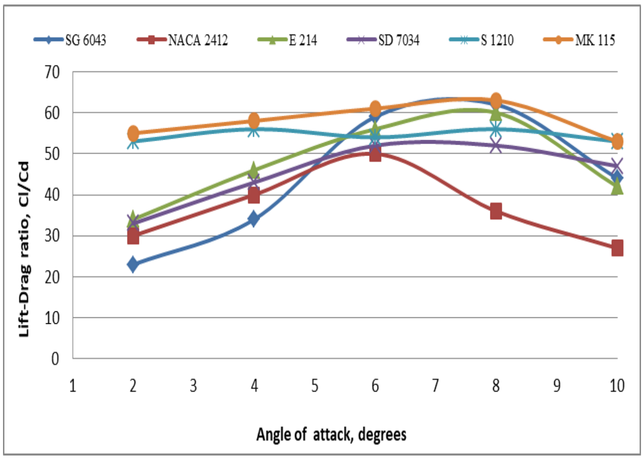

Fig. 25. Variations of lift-Drag ratios of different airfoils suited for small wind turbines at Re =100000

For angles of attack above 10 degrees the C_L for New airfoil (MK115) rapidly decreases. Finally it can be concluded that new airfoil (MK115) and SG6043 airfoil is most suitable for low wind speed applications. Fig. 18-21 shows the variation of lift coefficient (CL) with respect to different angles of attack for the selected airfoil. The new airfoil (MK115) have C_{Lmax} of 0.92, 1.25,1.69, 1.67 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0. SG6043 have C_{Lmax} of 0.81,1.5,1.5,1.47 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0.

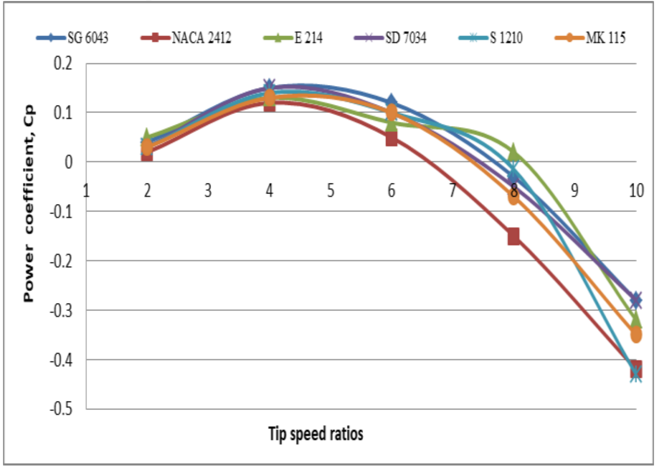

Fig. 26. Variations of Power coefficient of different airfoils suited for small wind turbines at Re =25000

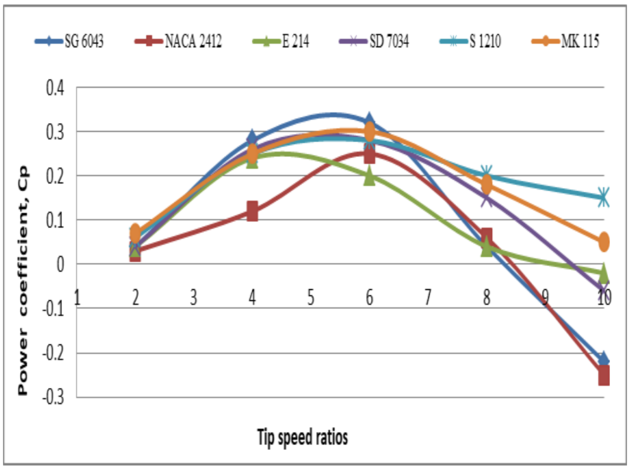

Fig. 27. Variations of Power coefficient of different airfoils suited for small wind turbines at Re =50000

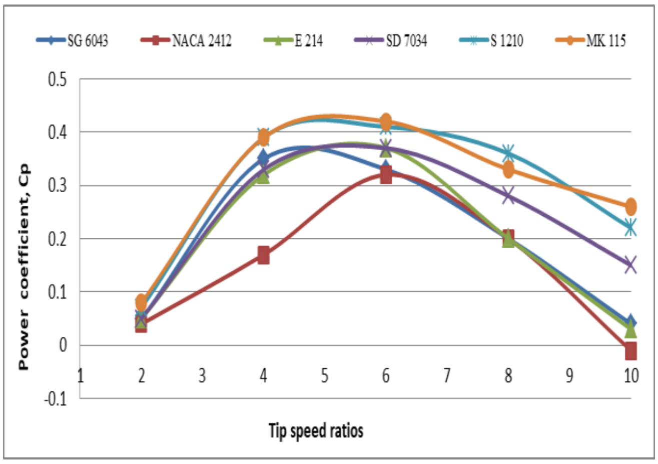

Fig. 28. Variations of Power coefficient of different airfoils suited for small wind turbines at Re =75000

SG6043 have C_{Lmax} of 0.81,1.5,1.5,1.47 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0. S1210 have C_{Lmax} of 0.98,1.28,1.87,1.9 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0. E214 have C_{Lmax} of 0.7, 1.32, 1.3, 1.32 at Re=25k, 50k, 75k and 100k for 10 degree angle of attack. NACA2412 have C_{Lmax} of 0.7,1.02,1.05,1.08 at Re=25k, 50k, 75k and 100k for an angle of attack is equal to 10^0. SD7034 have C_{Lmax} of 0.72,1.18,1.37,1.38 at Re=25k, 50k, 75k and 100k for 10 degree angle of attack.

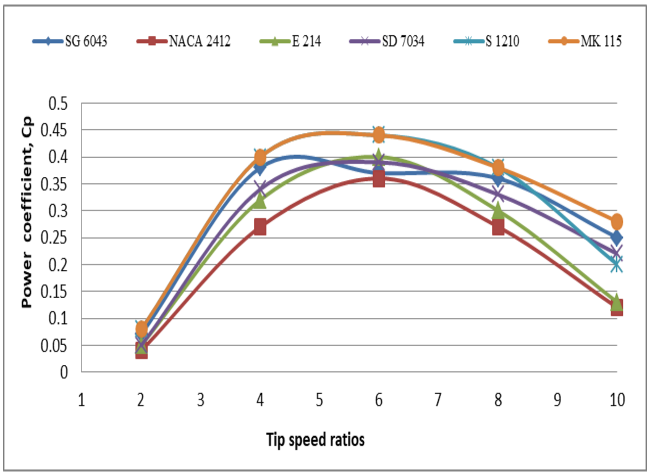

Fig. 29. Variations of Power coefficient of different airfoils suited for small wind turbines at Re =100000

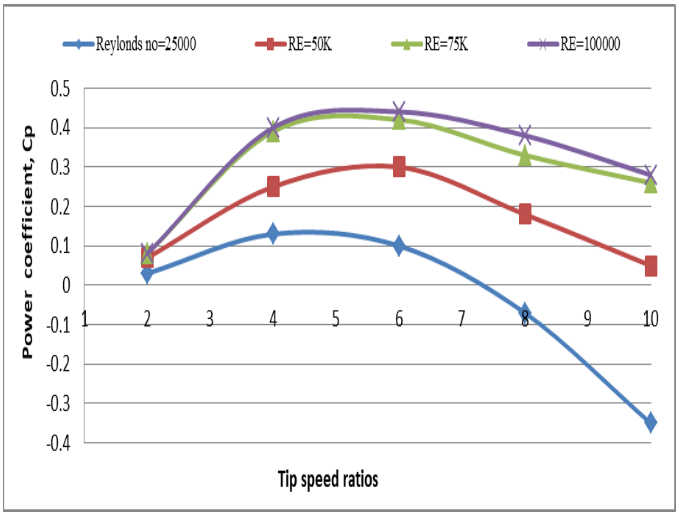

Fig. 30. Variations of Power coefficient of New airfoils (MK115) suited for small wind turbines at Re=25K, RE=50K, RE=75K and RE=100000

Fig. 22-25 shows the variation of lift to drag ratio (Cl/Cd) for various airfoil at Reynolds number values of 25k, 50k, 75k and 100k. From the graph, it was observed that the values of lift to drag ratio varies with respect to the changes in the angle of attack. A maximum lift to drag ratio (Cl/Cd) of 5.4,15,42,52 at Re=25k, 50k, 75k and 100k for SD7034 airfoil at angle of attack (α) $=8^0$. A maximum lift to drag ratio (Cl/Cd) of 8,34,53,62 at Re=25k, 50k, 75k and 100k for SG6043 airfoil at angle of attack (α) $=4^0,10^0,8^0,8^0$.A maximum lift to drag ratio (Cl/Cd) of 8,28,40,50 at Re=25k, 50k, 75k and 100k for NACA2412 airfoil at angle of attack (α) $=6^0,8^0,6^0,6^0$. A maximum lift to drag ratio (Cl/Cd) of 7,14,42,56 at Re=25k, 50k, 75k and 100k for S1210 airfoil at angle of attack (α) $=6^0$, 2^0, 8^0, 8^0.

A maximum lift to drag ratio (Cl/Cd) of 6.2,32,50,60 at Re=25k, 50k, 75k and 100k for E214 airfoil at angle of attack (α) =4^0, 10^0, 8^0, 8^0. A maximum lift to drag ratio (Cl/Cd) of 7,16,50,63 at Re=25k, 50k, 75k and 100k for New airfoil (MK115) at angle of attack (α) =4^0, 4^0, 8^0, 8^0. Therefore new airfoil (MK115), E214 and SG6043 airfoil is the best profile for small horizontal axis wind turbine to produce maximum power. It was observed that blade profile to produce maximum lift to drag ratio at an angle of attack is 8^0 for Re=75000 (75k) to 100000(100k) for selected airfoil in this research paper.

A. Power coefficient analysis of BEMT-blades at Re = 25000, 50000, 75000 and 100000.

The performance of a wind turbine blade profile is evaluated by determining its power coefficient (C_P). The power coefficient as a function of the tip speed ratio shown in Fig. 29-33 depicts the response of BEMT-blades at Re = 25000, 50000, 75000 and 100000 respectively. From Fig. 29-33, it can be observed that the values Cp initially increase with the increase in the value of tip speed ratio (λ), reaches the maximum, and then decreases. Furthermore, the blade rotors with a wider range of tip speed ratios offer high power coefficients. From the graphical representation, the BEMT-blades such as SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.15, 0.12, 0.13, 0.15, 0.14, and 0.17 at tip speed ratio (λ) =4 for Reynolds number is equal to 25000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.15, 0.12, 0.13, 0.15, 0.14, and 0.17 at tip speed ratio (λ) =4 for Reynolds number is equal to 25000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.32, 0.25, 0.2, 0.28, 0.28, and 0.28 at tip speed ratio (λ) =6 for Reynolds number is equal to 50000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.35, 0.32, 0.37, 0.37, 0.41, and 0.42 at tip speed ratio (λ) =6 for Reynolds number is equal to 75,000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have the Maximum C_p=0.37, 0.36, 0.4, 0.39, 0.44, and 0.44 at tip speed ratio (λ) =6 for Reynolds number is equal to 100000. Finally from the numerical and experimental simulation new airfoil performance was better as compared to other airfoil studied in this research paper. From the numerical simulation, MK115 airfoil blade was selected as the optimum blade due to its wide range of tip speed ratio from λ = 4 and 6 for 100 watt of small horizontal axis wind turbine at Re = 75000 to 100000. Numerical simulation of MK115 airfoil blade which was carried out at various Re values and variation of the power coefficient with respect to the different tip speed ratio are shown in Fig. 30. From the results, it was found that the maximum values of C_p obtained at tip speed ratio at 4 for Reynolds number is equal to 25000 to 50000, however the maximum Cp was obtained at tip speed ratio at 5 to 6 for Re =50000 to 100000 for all airfoil which are selected in this research paper. It was concluded that the lower Reynolds number (less than 50000) blade airfoil gives better results when tip speed ratio was less than 4 while higher Reynolds number blade airfoil gives better results when tip speed ratios is in between 5 to 6.

B. Rotor simulation of NACA2412, SG6043 and MK115 BEMT-blades at different blade angles

The performance of a wind turbine rotor is evaluated by determining its Mechanical power and Torque generated by turbine. The turbine power and Torque as a function of the wind velocity. The output power versus change of air velocity at blade angle is zero degree. It is clear that Mechanical power increases with increase in air velocity, it was concluded that MK115 blade profile gives better results as compared to the SG6043 and NACA2412 Airfoil. From results, shows the Torque versus air velocity of NACA 2412 at blade angle =0, 15 and 30 degree. It is clear that maximum torque obtained at blade angle=15 degree. NACA2412, Maximum Torque obtained 1.2113 Nm, 1.3433 Nm and 1.0914 Nm at blade angle =0, 15 and 30 degrees. SG6043, Maximum Torque obtained 2.1392 Nm, 1.4342 Nm and 2.404 Nm at blade angle =0, 15 and 30 degrees. MK115, Maximum Torque obtained 0.9744 Nm, 1.389 Nm and 2.4866 Nm at blade angle =0, 15 and 30 degrees. From graph results it is clear that blade angle directly effects on blade airfoil performance, it was concluded that NACA2412, SG6043 and MK115 blade airfoil produces maximum power at a blade angle is equal; to 15, 30 and 30 degree respectively. From Experimental results MK115 airfoil at blade angle-30 degree, it is clear that from results experimental values 10 % lower than theoretical values, however experimental results matched with Xfoil results. It is clear that the Torque increases with the increase in blade angle from (0.207 Nm) at (0^0) to (2.4866 Nm) at (30^0). Fig. 30 shows that Power coefficient versus Rotor shaft angle of MK115 airfoil. It is clear that from result graphs power coefficient decreases with increases rotor shaft angle. From Fig, 33, it was clear that power coefficient (C_p) =0.51, 0.5, 0.46, and 0.4 at Rotor shaft angle=0^0, 5^0, 10^0, and 15^0 respectively.

VII. CONCLUSION

This article introduces the layout, analysis and growth of the 100 Watt tiny horizontal axis wind turbine used at the low amount of Reynolds number, using Matlab and Xfoil software depending on core element flow hypothesis (BEMT) running at high wind speed. A, 20 distinct parts of 0.35 m blade width were used in Matlab software and Xfoil software, blade geometry and airfoil optimized. At distinct points of assault and tip speed ratio, the current job research and experimental investigation of distinct airfoils at small Reynolds number. The primary objective of this study job is to develop fresh airfoils operating at small wind speeds of wind turbine propellers on the lateral axis. The current job of creating and investigating suggested fresh airfoil operates at a small amount of Reynolds number. Aerodynamic parameters Investigation and manufacture of 6 airfoils were performed using Xfoil software at Reynolds number 25000, 50000, 75000 and 100000 in the current job. It was noted that the lift-drag proportions and energy coefficient readings are heavily affected by the attack angle and tip speed ratios respectively New Airfoil generates peak lift-drag proportions relative to Reynolds number SG 6043 airfoil equivalent to 100000. The airfoil SG6043, S1210 and New Airfoil (MK115) generates CLmax from 0.8 to 1.2 at 7 degrees to 10 degrees angle of attack. The CL for New airfoil (MK115) is rapidly decreasing for corners of assault above 10 degrees. Finally, it can be stated that fresh airfoil (MK115) and SG6043 airfoil are best suited for apps with small wind speed.

The latest airfoil (MK115) has a CLmax of 0.92, 1.25, 1.69, 1.67 at Re=25k, 50k, 75k, and 100k with an attack angle of 100. SG6043 have CLmax of 0.81,1.5,1.5,1.47 at Re=25k, 50k, 75k and 100k for an angle of assault equivalent to 100 fresh airfoil (MK115), E214 and SG6043 airfoil is the highest image for small wind turbine lateral shaft to generate peak energy. It has been noted that the blade curve for chosen airfoil in this research paper to generate peak lift-to-drag ratio at an angle of attack is 8 degree for Re=75000 (75k) to 100000(100k). SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have a maximum velocity range of Cp=0.15, 0.12, 0.13, 0.15, 0.14 and 0.17 for Reynolds number with a maximum velocity range of 25000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have a maximum velocity range of Cp=0.35, 0.32, 0.37, 0.37, 0.41 and 0.42 for Reynolds with a maximum velocity proportion of 75,000. SG6043, NACA2412, E214, SD7034, S1210 and MK115 (New airfoil) have a maximum velocity range of Cp=0.37, 0.36, 0.4, 0.39, 0.44 and 0.44 for the amount of Reynolds number equivalent to 100000 at tip speed ratio (λ) =6. Finally, fresh airfoil output was superior from the numerical and laboratory simulation relative to other airfoils investigated in this research paper. Clearly, the peak torque at slice angle=15 degree is achieved. NACA2412, Maximum torque at= 0, 15 and 30 degrees was 1.2113 Nm, 1.3433 Nm and 1.0914 Nm respectively. The maximum torque of SG6043 was 2.1392 Nm, 1.4342 Nm and 2.404 Nm at the angle of the blade= 0, 15 and 30 degree resp. MK115, Maximum torque was 0.9744 Nm, 1.389 Nm and 2.4866 Nm at= 0, 15 and 30 degree of blade angles respectively.

REFERENCES

1. A. Suresh and S. Rajakumar "Design of small horizontal axis wind turbine for low wind speed rural applications" Materials Today: Proceeding, March, 25, 2019.
2. Hirahara, H., and Nonomura Y., "Testing Basic Performance of a Very Small Wind Turbine Designed For Multi Purposes" Renewable Energy, 30, 2005, pp. 1279-1297.
3. Chandrala, M., Choubey, A., and Gupta, B. , " Aerodynamic Analysis of horizontal axis wind turbine blade" Journal of Engineering Research and Application , Vol. 2, 2012, pp. 1244-1248.
4. Bai, C. J., Hsiao, F. B., Li, M. H., Huang, G.Y., and Chen, Y. J., "Design of 10 kW Horizontal –Axis Wind Turbine (HAWT) Blade & Aerodynamic Investigation Using Numerical Simulation" Journal of Procedia Engineering, 67, 2013, pp. 279-287
5. Almukhtar, Ali. H., "Effect of Drag on The Performance For an Efficient Wind Turbine Blade Design" Journal of Energy Procedia, 18, 2012, pp. 404-415.
6. Singh, R. K., Ahmed, M. R., Zullah, M. A., and Lee, Young- Ho., " Design of a Low Reynold's Number Airfoil For Small Horizontal Axis Wind Turbines" Renewable Energy, 42, 2012, pp. 66-76.
7. Wright, A.K., and Wood, D.H., "The Starting and Low Wind Speed Behaviour of A Small Horizontal Axis Wind Turbine," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 92, 2004, pp. 1265-1279.
8. Maalawi, K.Y., and Badr, M.A., "A Practical Approach For Selecting Optimum Wind Rotors," Renewable Energy, 28, 2003, pp. 803-822.
9. Suresh A. and Rajakumar S. "Design of small horizontal axis wind turbine for low wind speed rural applications" Materials Today, Published by: Elsevier
10. Mohamed Khaled, Mostafa Mohamed Imran, Hesham Eisayed Abdel Hamed, Ahmed Farouk and Abdel Gawad "Aerodynamic Design and Blade Angle Analysis of a Small Horizontal–Axis Wind Turbine" American Journal of Modern Energy, 2017; 3(2): 23-37
11. N. Karthikeyan, K. Kalidasa Murugaval, S Arun Kumar and S. RajakumarReview of aerodynamic developments on small horizontal axis wind turbine blade, Renewable and Sustainable Energy Reviews, Vol. 42, 2015, pp. 801-822
12. Farhang Momeni, Sabzpoushan Sayedali, Valizadeh Reza, Morad Mohammad Reza, Liu Xun and Ni Jun, Plant leaf-mimetic smart wind turbine blades by 4D printing, Renewable Energy, Vol. 130, 2019, pp. 329-351
13. Chaudhary, M.K. and Roy, A., Design and optimization of a small wind turbine blade for operation at low wind speed. World Journal of Engineering, Vol. 12, No. 1, 2015, pp. 83-94
14. Singh, R.K. and Ahamed, M.R., "Blade Design and Performance Testing of a Small Wind Turbine Rotor For Low Wind Speed Application" Renewable Energy, Vol. 50, 2013, PP 812-819.

AUTHORS PROFILE

Manoj Kumar Chaudhary is pursuing his PhD in Mechanical Engineering from the Sathyabama Institute of Science and Technology; Chennai was enrolled in the 2016 session. He received the M.E. degree in Mechanical Engineering from the G H Raisoni College of Engineering & Management, Pune India, in 2014, and the B.E. degree in Mechanical engineering from the G. H. Raisoni College of Engineering, Nagpur, India, in 2011. He is currently assistant professor of Mechanical engineering at the Dr. D. Y. Patil School of Engineering, Pune (India). He has over 8 years of total academic teaching experience with over 9 International Journal Publications and 9 International Conferences, 5 National Journals and 5 National Conferences, with Renewable Energy, Heat Transfer, Ocean Energy, Refrigeration and Air Conditioning as his research area. He is a reviewer of the American Journal of Energy Engineering (AJEE). He is a Guest Editor for Renewable Energy Resources and Power Generation "He is a Guest Editor for the Special Issue" "Smart Manufacturing and Smart Factory" "as well as" Guest Editor for the Special Issue of "Advances in Joining and Surface Engineering Materials." He is a DST and Texas Instruments India Innovation Challenge as a Faculty Mentor. He is an Editorial Board Members in SIREA journal of Mechanical Engineering.

Prakash Subramanian was born in Pollachi, India, in 1969. He received the B.E. degree in Production Engineering from the P.S.G college of Technology Coimbatore, India, in 1990, and the M.E. and Ph.D. degrees in Mechanical engineering from the Sathyabama University, Chennai India, in 2000 and 2010, respectively. He is currently a Professor and Dean in the School of Mechanical Engineering, Sathyabama University, India, and has been the Head of the department Mechanical Production Engineering since 2015. From 2011 to 2015, he was the Professor in the Department of Mechanical Engineering, Sathyabama University. Since 2000, he has been the Associate Professor in Faculty of Mechanical Engineering Sathyabama University. He is a member and Chairman of IIPE and an observer in CIDO fall meeting, Malaysia. He has published more than 75 scientific papers and books in the field of materials for Mechanical engineering and Composites and granted with 4 patents His research interests include machining of composites, optimization, Welding and Self-healing composites. He is a Life Member of the Indian Society for Technical Education (ISTE), Indian Institute of Production Engineers (IIPE) Chennai chapter. He was the Chair person and Key note speaker of the APM International Conference on materials held in Chennai, Bangalore and Bhubaneswar. He was the recipient of the Best Faculty Award from the University of Sathyabama in 1999, 2006, 2008 and 2011. He was the recipient of the Best Research Supervisor Award from the IARA and ASDF in 2018.