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Abstract- *Wind energy, being easily accessible, environmentally friendly, and being cost effectively, has become the world's one of popular growing renewable energy sources of electricity generation. Among all of the wind turbines, Horizontal Axis Wind Turbine (HAWT) is considered as leading technology due to its high efficiency. However, to spread this technology to mankind it is needed to develop turbine in this way that people can use it individually and comfortably. This kind of thinking accelerates the advancement of integration of wind turbine with Nano grid concept. Although great progress has been achieved in the wind technology, there is still scope to reduce the cost and improve the performance of small-scale wind turbines. Moreover, low wind velocity should also need to be utilized properly to achieve saturated energy production. So, concentration is going to small scale wind. Small scale horizontal axis wind turbines (SSHAWT) provide a clean, prospective and viable option for energy supply. Moreover, SSHAWT can also be acted as one of the reliable power sources of Nano grid. To design efficient wind turbine it is required a smooth and continuous development process. The current study focused on aerodynamic design and performance analysis of small-scale horizontal axis wind turbine blade using the blade element momentum (BEM) method with most updated and corrected model. The effects of the design parameters of a small wind turbine such as the blade chord and twist angle distributions on power performance were also investigated. In this study, the pitch is fixed and speed is variable. Results show that the maximum coefficient of performance is .5089 at the Tip speed ratio 6.5 which is very indication in preliminary stage power prediction.*

Keywords: Energy, Renewable Energy, Wind Turbine, Small Scale, Blade Design, BEM, Nano-Grid, Power Systems.

1. INTRODUCTION

The utilization of energy resources has played a key role in the development of human Civilization. Now one of the greatest challenges in a modern century is to find out the reliable energy source. Conventional energy sources such as natural gas, coal, and fossil fuel have accelerated industrialization and modernization of different nations. But the consternation around the world is that the emission of carbon dioxide into the atmosphere produced due to these traditional sources is the number one offender for the climate change. So today's burning question is that, besides producing sufficient energy for mankind could we able to ensure a safe world for next generation? Hence, it should be committed to finding out the solution of using alternative energy resources besides the conventional sources. For this reason, renewable and sustainable energy is getting attention in current research. It is noticeable that about 13.44 percent of total U.S. domestic electricity generation comes from renewable energy sources [1]. And among the renewable sources, wind power can be considered as a never end potential renewable energy resource. Therefore wind turbine technology can be utilized as a prime mover operated by such type of renewable energy source. According to the American Wind Energy Association, the current installed wind power capacity by the end of 2015 in the US is approximately 73992 MW [2].

Commercial wind turbines have increased significantly in size, which has resulted in more energy being extracted from the wind. But the fact is the availability of wind speed is not sufficient for all places. That's why it is time to think about the adaptive technology with small-scale wind energy. Small- scale horizontal axis wind turbine (HAWT), which capacity range from 1kW to 100 kW electric power, is relatively simple, cost effective and easy to access than a large-scale turbine in both design and construction [3]. Moreover, to ensure power quality, peak load minimization, transmission, and distribution losses reduction and independent power source Nano grid concept have employed. Small wind turbines can be integrated with Nano grid to utilize On-grid and off-grid applications [4]. It is regarded that small wind turbines will have a significant role in power distribution network. It is recommended that for a reliable source of energy and smooth running system the first and foremost step is to design an efficient turbine model. However, challenges with wind turbine are getting visible in the experimental and practical environment by trial and error method. Rather, it is good practice to analyze the system by a well-established computational method.

For horizontal axis wind turbine the most significant part is blade geometry. For small scale, various types of blade geometry were developed where, sometimes blade cross-sections are made by the airfoil, sometimes not. Hirahara, Hiroyuki, et al. Developed and tested very small wind turbine of 500 mm rotor diameter. As the size of the turbine is very small, the blade is designed for fan type instead of taper blade. The cross-section of the blade is followed by NACA 2404 template. Experimentally, the rated power coefficient of this turbine was 0.35 and optimum driving condition to speed ratio is 2.7 [5]. As this kind of micro wind turbine has small power capacity, there will be needed more than one wind turbine to fulfill power requirement for a small unit like household activities. Rather than that, it could be possible to enhance capacity by increasing diameter of the turbine but still in small range. Goundar et al. designed a three bladed 10 m diameter HAWT and then predicted the performance using BEM method. This turbine had tip speed ratio 4, and the maximum efficiency was 47.6% with the 2 m/s wind speed [6]. Watanabe et al. concentrated on shape optimum design of small HAWT blade operating in low Reynold number. In this work coefficient of performance is predicted by BEM where three-dimensional blade shape is directly provided. Here the performance improvement is 4% compared to the experimental wind tunnel data [7]. It is clear that with low wind velocity and small radius the output power of the wind turbine is very low which is not usable in daily household activity as well as the performance of small wind turbine is also very poor. So concentration goes to other parameters such as Reynold number, airfoil design, and selection. Ronit et al. designed a special airfoil for low Reynold number which is used a two-bladed wind turbine. Here the coefficient of performance is 0.255 at height 8.22 m at a wind speed of 6 m/s and pitch angle 18 degrees [8]. In this work, parameters are adjusted to get sufficient output power although operating with low wind velocity. The expected output power of this work is fixed at 10 kW, and according to this the radius and others design parameters are determined. After that, the performance analysis is done by Blade Element Momentum (BEM) method. And for the analysis the S833 airfoil is used which is developed by NREL, especially for a wind turbine.

2. SMALL SCALE WIND TURBINE AND SCOPE OF SMALL WIND

Nowadays, the wind turbine is designed, for both large and small scale, according to the application field. Technically there are several definitions of the small-scale wind turbine. The most important international standardization body, the IEC, defines SWTs in standard IEC 61400-2 as having a rotor swept area of less than 200 m^2, equating to a rated power of approximately 50 kW generating at a voltage below 1000 V AC or 1500 V DC [9]. Moreover small wind turbines are classified as micro (1 kW), mid-range (5 kW) and mini wind turbine

(20kW+) [10]. Due to flexibility of installation and to catch up the world's small scale wind potential small scale wind turbines are getting more popular. From the world small wind report,2015 it is showed that at the end of 2013, a cumulative total of at least 870'000 small wind turbines were installed all over the world. In terms of install capacity China, USA, UK are in leading position. Their percentages of the global capacity are 41%, 30% and 15% correspondingly [9].

3. SCHAWT BLADE DESIGN

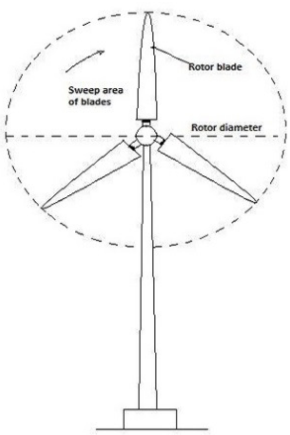
In a horizontal axis wind turbine the one of the key prime over is the blade. As compared to the large scale wind turbine small scale wind turbine blade is not so complicated. Usually, large wind turbine blades are made of two or more combination of airfoil shapes wherein small scale one airfoil is enough to build whole blade geometry. Instead of variable pitch angle as like a large wind turbine, this work focuses on fixed pitch angle with variable wind speed. However, in design procedure, the main parameters such as rated wind speed, rotor diameter, airfoil type, and tip speed ratio should be considered first before conducting blade geometry.

3.1 Rotor Diameter

The diameter of the wind turbine rotor primarily depends on the expected power and wind condition where the wind turbine will be installed. The diameter of small wind turbine is selected in such a way that it will ensure the rotation with low wind speed as well as will maintain proper strength of the total structure and blades At the beginning of design procedure, it is recommended to assume an approximate expected power which would be the output of the wind turbine. From the expected power equation the radius of the wind turbine can be calculated

$$R = [\frac{2P_D}{C_{PD}\eta_d\eta_g\rho_a\pi V_D^3}]^{\frac{1}{2}} \qquad (1)$$

Where,C_{PD} is the design power coefficient of the rotor, η_d is the drive train efficiency, η_g is the generator efficiency, V_D is the design wind velocity. The design power coefficient C_{PD} range is 0.4 to 0.45. The combined efficiency of drive train and generator is considered 0.9 [11]. Radius of the wind turbine depends on the expected power and wind velocity. By fixing expected power 10 kW the variation of radius with the wind velocity is showed in figure 2.



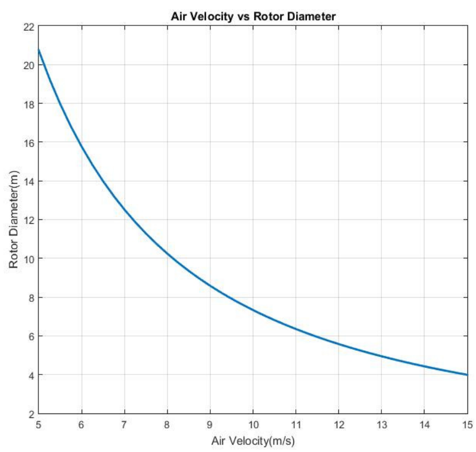


Figure 1: HAWT diameter Figure 2: Variation of Rotor Diameter with Air Velocity

3.2 Rated and Design Wind Speed

The rated wind speed is the wind speed at which the wind turbine is generating its rated power. From the power equation, it is showed that the wind power is proportional to the cube of the wind speed. However, a higher rated wind speed is not always appropriate as the annual power output is also a function of the local wind speed distribution. It can be described as Weibull distribution with a shape parameter and scale parameter. The annual power output can be calculated as:

$$P_{annual} = 8760 * \frac{1}{2}\rho A\eta C_{p,o}\int_{cut\ in}^{rated} v^3 f_{rayleigh}(v)dv + 8760 * P\int_{cut\ in}^{cut\ out} f_{Rayleigh}(v)dv$$
(2)

Where A is wind turbine rotor area, η is efficiency including mechanical and electrical efficiency, $C_{p,o}$ is the maximum power coefficient of the blade, $f_{Reliegh}\ (v)$ and is the Rayleigh wind speed distribution, which is defined as:

$$f_{Reliegh}\ (v) = \frac{\pi}{2}\frac{v}{\overline{v}^2}\exp(-\frac{\pi}{4}\frac{v}{\overline{v}^2}) \quad (3)$$

Here $\overline{v}$ is the annual mean wind speed. It was found that lower rated wind speed leads to higher AEP for fixed pitch variable speed wind turbine [12]. On the other hand the wind speed which is consider for design a wind turbine is called design wind speed. Usually wind speed below 2 m/s or 3 m/s are not suitable to produce significant amounts of electricity generation. To design a small wind turbine it is important to check the availability of wind speed is available at near to the ground level.

3.3 Airfoil Selection

Different types of airfoil shapes are available for both traditional aviation and wind turbine technology. With the development of interest in wind energy sector, some dedicated airfoils have been designed. For small wind turbines, airfoils are not as critical for performance as they are for large wind turbines. But there are only a few in numbers of airfoil shapes which are suitable for designing small-scale wind turbine. For small scale wind turbine the airfoils should be used at a low angle of attack, where the coefficient of drag is much lower as compared to the lift coefficient. Traditional NACA series airfoils were developed for aviation technology, but nowadays some NACA series airfoils are also used for wind turbine blade. The S8 series airfoils, which were designed by National Renewable Energy Laboratory (NREL) in the USA, are popular in stall-regulated wind turbine blades due to their gentle stall condition [13]. The FFA W series airfoil was developed in Sweden. These airfoils were initially designed for large wind turbine such 45 m diameter rotor size. For low Reynold number, Risø series from Denmark are popular [14]. Another popular airfoil series is DU series. These were designed in the Netherlands, are popular in middle and high Reynolds number [15]. Some special type of airfoils such as SG605X series were designed by Selig/Gigere from the University of Illinois at Urbana-Champaign. These airfoils are popular due to their high lift coefficient and the ability of operation in low Reynold number wind condition which means these airfoils are suitable for small horizontal axis wind turbine [16]. To select the appropriate airfoil for small wind turbine some parameters should be maintained such as thickness, the coefficient of lift, the coefficient of drag, stiffness in the blade root section and so on. Usually, the airfoils are tested practically in a wind tunnel within a range of Reynolds numbers and surface conditions. To predict aerodynamic performance other several software applications such as Xfoil, are used. These are developed according to potential flow techniques. Moreover, CFD is also a popular method of aerodynamic performance analysis. The aim of the aerodynamic analysis to determine the optimum angle of attack. In this work, Airfoil S833 is used to design blade geometry which is invented by

NREL. This special kind of airfoil is made for a small-scale wind turbine. Dan M and et al. have investigated different effects such as Reynold Number effect, roughness effect on S833 airfoil. From the Pennsylvania State University Low-speed, Low-Turbulence Wind Tunnel test the maximum lift coefficient for the design Reynolds Number of $0.4x10^6$ is estimated to be 1.10. For the same Reynold number condition, the maximum lift coefficient increased 1 percent from transition free to the fixed condition. On the other hand for the rough condition, this increment was 3 percent. So by summarizing the S833 airfoil have achieved a high maximum coefficient of lift and low profile-drag coefficient and this airfoil should reveal docile stall characteristics to meet the design goal Moreover the zero-lift pitching-moment coefficient and this airfoil thickness have been fulfilled [13]. Figure 3 shows the shape of S833 airfoil.

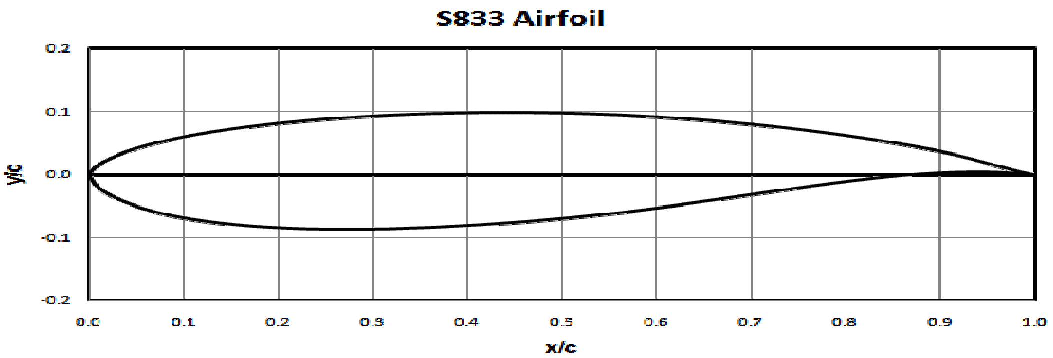


Figure 3: Relative Coordinate of Airfoil S833 [17]

3.4 Reynold Number

Reynold number is a very vital parameter to determine the wind turbine operating condition and aerodynamic behavior of the wind, The Reynold number is found by using the equation given below Where: V_{rel} is the relative wind speed (m/s), c is chord length (m), ν is kinematic viscosity of air ($\nu = 1.511\times10^{-5}$) (m²/s) at20^0C.

$$Re = \frac{V_{rel}C}{\nu} \qquad (4)$$

The small wind turbine typically operates in the wind speed between 5 m/s to 30 m/s. From the analysis of different existing small wind turbine chord distribution, it is clear that the chord distribution varied from .05m to .5m. It depends on the size of the wind turbine and airfoil specification. Considering all variables, the assumed Reynold number range for a small scale wind turbine is usually between 100000 and 400000 [18_19].

3.5 Aerodynamic Characteristics

According to the principle of HAWT operation, the key force to rotate the turbine is lifted force, which is generated by the airfoil cross section. Figure 4 describes these terminologies of airfoils, where φ is relative angle between air flow stream line and axis of rotation, α is angle of attack which is angle between air flow stream line and chord line, ϴ is pitch angle.

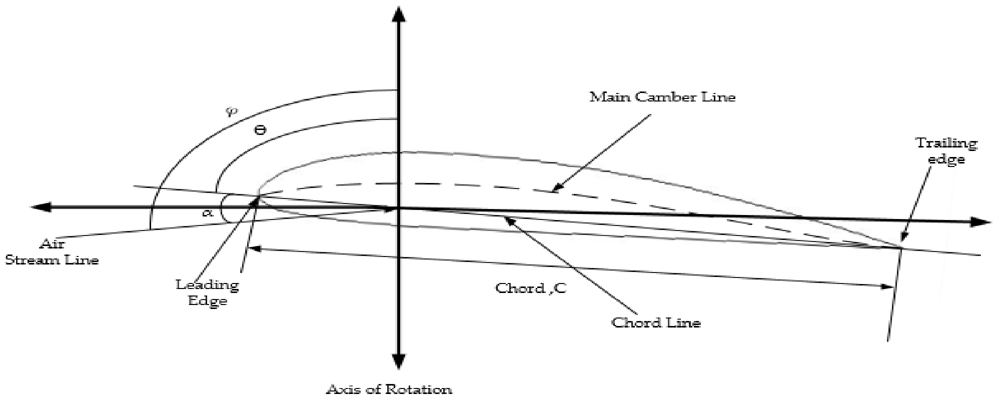


Figure4: Basic Terms of Airfoil Geometry

To analyze aerodynamic characteristics of the airfoil first of all need to get the optimum angle of attack. For an initial guess, a 2D polar coordinate XFOIL software is used for the analysis. Here S833 airfoil was tested for four different Reynold numbers.

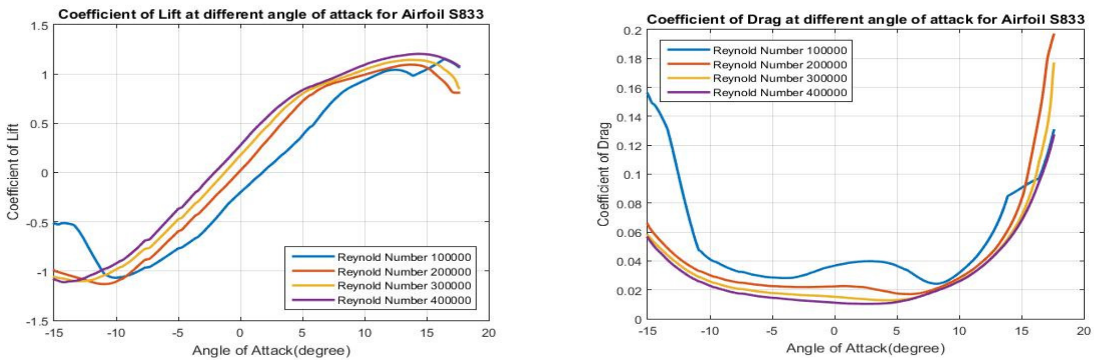


Figure 5: Variation of Coefficient of lift and drag with Angle of Attack

As this work focused on small-scale wind energy, it recommended considering air velocity is very low. And considering low wind velocity Reynold number, 200000 is best fit for analysis. At this condition from the figure 8, it is showed that at an angle of attack 7^0 the coefficient of lift is 0.88 which is considered most optimum coefficient for airfoil S833. Another vital parameter is the coefficient of drag. Figure 5 shows the variation of coefficient of lift and drag with different Reynold numbers. It is noticed that for the Reynold number 100000 the values of coefficient of drag are higher as compared to other Reynold numbers. From the curve, for Reynold number 200000 it can be said that the coefficient of drag is very low at an angle of attack 7^0 and the value of the coefficient of drag is 0.01792.Other than two case studies discussed above figure 6 explain the ratio of coefficient of lift and drag with four smaller scale Reynold number.

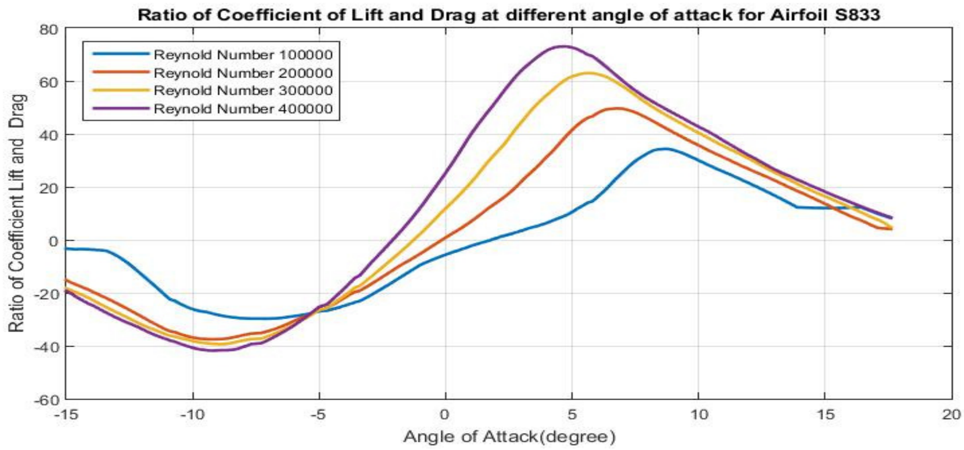


Figure 6: Ratio of coefficient of lift and drag with different Angle of Attack

From the figure above it is observed that that at Reynold number 200000, the pick of the coefficient's ratio is maximum for the angle of attack 7^0. So in summary angle of attack 7^0 is the best choice to design a wind turbine blade with S833 airfoil at low Reynold number.

3.6 Tip Speed Ratio

Tip speed ratio is introduced to define the relation between blade angular speed and air velocity; the equation 5 defines the tip speed ratio.

$$\lambda = \frac{\omega R}{V} \qquad (5)$$

Where ω angular velocity of the rotor, R is radius and V is wind speed. The tip speed ratio leads higher rotation of turbine. Whenever the rotational speed is higher the efficiency of the turbine is higher and less material is needed to make blade. For high tip speed ratio smaller gear boxes are required but sophisticated airfoil shapers are need to be selected. For electrical power generation the range of the tip speed ratio is $4< \lambda<10$. To determine the optimum value of tip speed ratio, the empirical relation between power coefficient and tip speed ratio was developed initially [20]. After that a, similar procedure to assess optimum tip speed ratio for different airfoils with different blade numbers was developed by Artificial Neural Network. According to that method the power coefficient is a function of TSR, blade number and maximum lift/drag ratio [21].

$$C_p = C_{pSchemitz}\,(1 - \frac{\lambda}{\frac{Cl}{Cd}})(1 - \frac{1.84}{B*\lambda}) \qquad (6)$$

Here, $C_{pSchemitz}$ is Schmitz power coefficient, which is 0.5926, B is the blade number, Among all the horizontal axis wind turbine the three bladed turbine are mostly balanced and economical for optimum design. And $\frac{Cl}{Cd}$ is the maximum lift to drag ratio. To get the appropriate tip speed ratio figure 7 shows the relation between coefficient performance and tip speed ratio at different Reynold number.

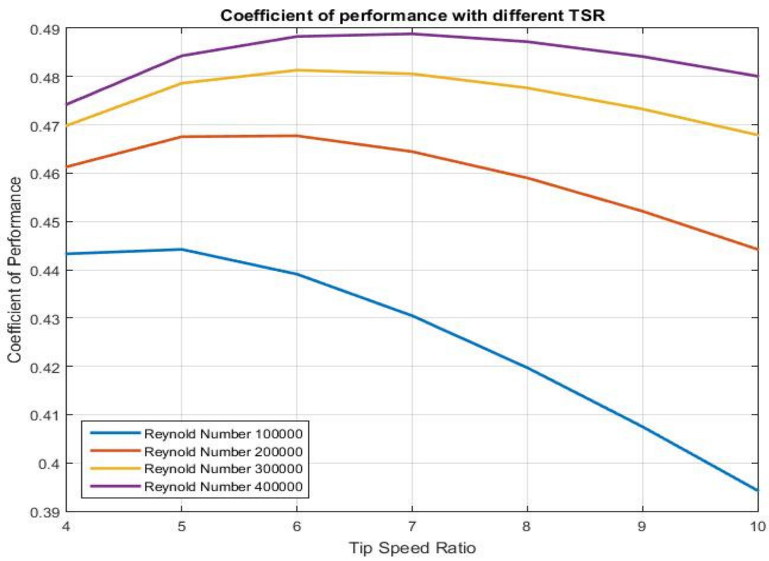


Figure 7: Variation of Coefficient of Performance with Tip Speed Ratio at different Reynold Number

From the figure, the best coefficient of performance is 0.4957 at Tip speed ratio 6.5. And it is pretty much same as all Reynold number mentioned in the figure. For this tip speed ratio, the blade geometry parameters are selected for further consideration. It is essential to determine whether the turbines would be operating at a fixed rotational speed or variable rotational speed. For a high tip speed ratio, the geometry of the blade would require a long, slender shape. However, a low tip speed ratio like this work wind turbine would be the opposite. It requires a short, thicker blade. Wind turbines cannot always operate at optimum tip speed ratio all the time, but for a range of wind speeds, the turbines operate at different tip speed ratios. If the wind turbine were to operate at a tip speed ratio other than the optimum tip speed ratio, then the performance of the turbine would significantly be less than the optimum performance for which the turbine is designed.

3.7 Blade Geometry

An important design feature of a wind turbine is the blade geometry as it is responsible for the extraction of kinetic energy from the wind and optimizing wind turbine blades is to maximize power output and efficiency. To determine the distribution of the cross-sectional shape of the blade, some design parameters are required to satisfy the requirements of the BEM theory equation. Once these parameters are selected, it will result in the extrapolation of chord distribution and twist distribution of a blade which closely resembles the Betz limit power production ideal blade. The initial design equation of relative angle and chord for any airfoil can be obtained from the equations 7 and 8.

$$\varphi = \frac{2}{3} tan^{-1}(\frac{R}{\lambda_r}) \qquad (7)$$

$$c = \frac{16\pi r}{BC_l} sin^2(\frac{2}{3} tan^{-1}(\frac{R}{\lambda_r})) \qquad (8)$$

Initial values were used to calculate the performance of the turbine by BEM. This an iterative process. Whenever the optimum value of the coefficient of performance is come up for every section of the blade, the associated relative angle and chords were selected as the optimum value. Blade geometry does not only depend on the chord length and twists angle but also the material of the blade. Beside the maintaining aerodynamic characteristics it also important to ensure the proper strength of the blade. Because of continuous rotation, wind turbine blade faces cyclic loading and thus fatigue and crack formation present safety concerns. In most of the cases wind turbine blades facing harsh environment, constantly varying wind loads, temperature and humidity changes, erosion and corrosion. So Wind turbine blades should be designed considering all factors. After considering all parameters discussed above the initial design parameters are given in table1.

Table 1: Initial Blade design parameters

Wind Velocity(m/s)	Diameter (m)	Tip Speed Ratio	Blade Number	Initial AOA	Initial Coefficient of lift	Inner Diameter
7	11	6.5	3	7	0.88	0.2

The wind turbine blade is not uniform throughout the length. The blade was divided into ten segments including hub section. After applying optimization technique for each section, the calculated parameters are given in Table 2, where values are dimensionless. By using this dimensionless values it possible to make wind turbine blade for different diameter.

Table 2: Optimized Blade Geometry Parameters

Blade Segment	Relative Radius	Relative Chord	Relative Angle	AOA	Twist Angle	Power (kW)
1	0	Hub	Hub	Hub	Hub	Hub
2	0.15	0.1974	27.49	4.01	23.48	.2315
3	0.25	0.1591	19.87	5.80	14.07	.568
4	0.35	0.1262	14.76	5.94	8.82	.811
5	0.45	0.1029	11.66	6.07	5.59	1.03
6	0.55	0.0863	9.60	6.19	3.41	1.25
7	0.65	0.0741	8.15	6.27	1.88	1.44
8	0.75	0.0649	7.02	6.29	0.73	1.61
9	0.85	0.0576	6.08	6.24	-0.16	1.71
10	0.95	0.0518	4.69	5.54	-0.85	1.46

The blade segments are divided in such a way that the hub covers 15% of swept radius. However, there is a reference point at the middle of every section. Chords, angles of attack, twist angles are calculated on these points for all sections. From the chord distribution, it is showed that the maximum chord length is in the 2nd section. After that, the chord length is decreased step by step till the tip of the blade. On the other hand twist angle is maximum at the very beginning section close to the hub and after that values are continuing as decreasing order up to the tip. Figure 8 shows the chord distribution throughout the radius. For manufacturing the blade sometimes it is needed to linearize the values of chord length.

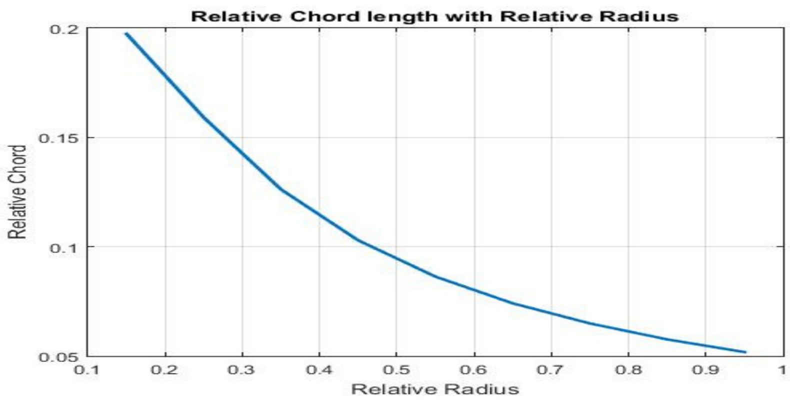


Figure 8: Variation of Relative chord with Relative Radius

4. BLADE PERFORMANCE ANALYSIS USING BEM METHOD

To determine the blade performance the Blade Element Moment (BEM) based approach has been widely researched and reported to be acceptably efficient one. This method combines the Momentum theory and Blade Element Theory. Momentum theory is used to determine forces acting on the rotor to produce the motion of the fluid. On the other hand, blade element theory determines the forces on the blade as a result of the motion of the fluid regarding blade geometry. In this method, the wind turbine blades are divided into annular blade elements. After that one-dimensional linear momentum conservation is applied to all annular elements which lead to the forces and power calculation. These calculations are based on the sectional aerodynamic characteristics data, the chords and twist angles of the blade geometry. The airfoil aerodynamic characteristic data such as coefficient of lift and drag could be obtained from wind tunnel measurements or different types of polar coordinate software like xfoil. The description of the airfoil aerodynamic characteristics at both low angle of attack and high angle of attack are inevitable in the BEM method. Different lift and drag data directly lead to different power output results. In the iterative procedure of BEM, for every element of the blade, the lift and drag coefficients are expected to have a general mathematical model for a high range angle of attack as well as for a whole range wind speed analysis at yawed or un-yawed conditions. At normal operating conditions such as idling, starting, pre-stall, stall, and deep stall stages the aerodynamic characteristics are also needed to be obtained from the different angle of attacks. Different types of global stall model for determining the airfoil characteristics are developed. But sometimes these models are too unpredictable for specific wind turbine airfoil analysis. Among all of models Viterna-Corrigan model is one of the widely used model [22]. Viterna's equations for the coefficient of lift and drag are as follows:

$$C_l = A_1 \sin(2\alpha) + \frac{A_2 cos^2\alpha}{sin^2\alpha} \quad (9)$$

$$C_d = B_1 sin^2\alpha + B_2 cos\alpha \quad (10)$$

Where, $A_1 = \frac{B_1}{2}$

$$A_2 = (C_L - C_{DMAX} sin\alpha_s cos\alpha_s)\frac{sin\alpha_s}{cos^2\alpha_s} \quad (11)$$

$$B_1 = C_{DMAX} \quad (14)$$

$$B_2 = C_{D_s} - \frac{C_{DMAX} sin^2\alpha_s}{cos\alpha_s} \quad (12)$$

$$C_{DMAX} = 1.11 + 0.18AR \quad (13)$$

Here, C_l and C_d are coefficient of lift and drag respectively. And α represents angle of attack. However to characterize "stall delay" phenomena several empirical model have been developed. Another important factor of BEM is induction factor which can be described by the axial induced velocity and tangential induced velocity. By using the differential thrust with blade element theory it is possible to determine the axial induction factor

$$C_x = C_l * sin\emptyset - C_d * cos\emptyset \quad (14)$$

$$C_y = C_l * cos\emptyset + C_d * sin\emptyset \quad (15)$$

$$\frac{a}{a-1} = \frac{\sigma C_y}{4sin^2\emptyset} \quad (16)$$

Here, $\emptyset$ is the relative angle and a defined as axial induction factor. However, by using differential torque with angular momentum theory the tangential induction factor a'can be expressed as

$$\frac{a'}{a'+1} = \frac{\sigma C_x}{4\, sin\emptyset\, cos\emptyset} \quad (17)$$

Where solidity ratio σ is defined by,

$$\sigma = \frac{cB}{2\pi r} \quad (18)$$

Here, c, B, r represent chord length, blade number and local radius of the turbine blade respectively. At the tip of the wind turbine blade, the air flow radially inward direction over the blade tip, creating an obstacle for the circulation of air. This causes reduction of the torque and turbine efficiency. To reduce the loss of torque, Prandtl developed a method to calculate the radial flow effect near the blade tip which is considered much accurate for high tip speed ratios [23]. The Prandtl's factor is defined by

$$F_p = \frac{2}{\pi} cos^{-1}(e^{-f}) \quad (19)$$

$$\text{Where, } f = \frac{B}{2}\frac{R-r}{rsin\emptyset}$$

Applying Prandtl tip loss correction factor the final two induction factors are expressed as

$$a = \frac{1}{\frac{4Fpsin^2\emptyset}{\sigma C_y}+1} \quad (20)$$

$$a' = \frac{1}{\frac{4Fpsin\emptyset cos\emptyset}{\sigma C_x}-1} \quad (21)$$

The induction factor getting by Prandtl tip loss correction factor is only accurate for the value less than 0.2. If the induction factor value is greater than 0.2, it needs to use Glaurt average axial interference factor [23].

$$a = \frac{1}{2}(2 + K(1 - 2a_c) - \sqrt{(K(1 - 2a_c) + 2)^2 + 4(Ka_c^2 - 1)} \quad (22)$$

$$\text{Where, } K = \frac{4Fsin^2\emptyset}{\sigma C_y}$$

Whole BEM method is developed by Matlab coding where different segments need different iteration number. The algorithm for the BEM method is given in figure 9.

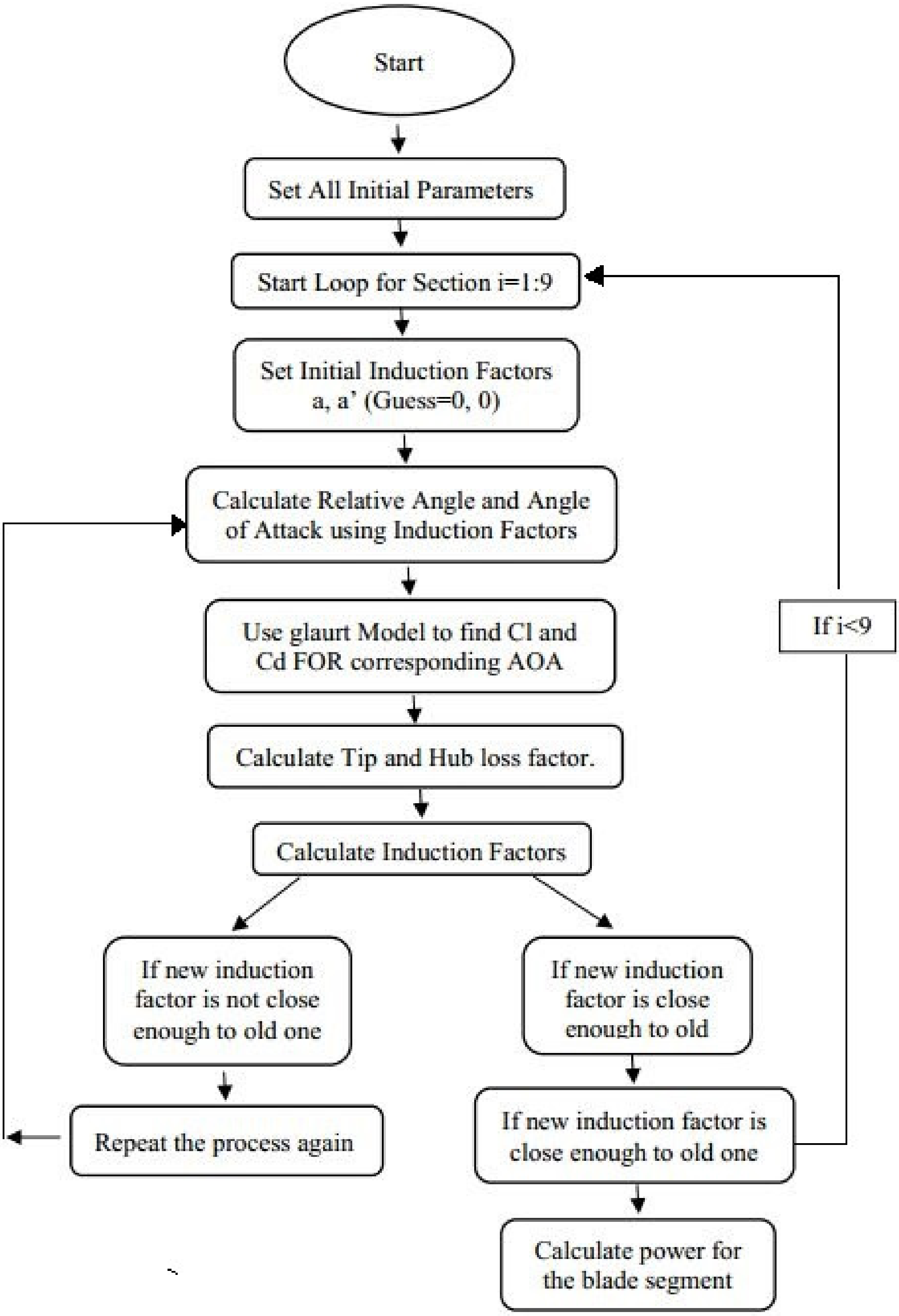


Figure 9: Algorithm for the BEM method

To get the power for each section of the blade first need to calculate Relative speed which can be represented by

$$U_{rel} = v * \frac{1-a}{\sin \emptyset} \quad (23)$$

After that tangential force and power for each section can be calculated by the following equations.

$$F_{tangential} = 0.5 * \rho_{air} * U_{rel}^2 * c * c_x \quad (24)$$

$$P_{section} = \omega * B * t * F_{tangential} * r \quad (25)$$

After computing power for all sections of the blade, the values were added to get whole power for the whole blade. Following equations are used to calculate maximum power, efficiency, and coefficient of performance.

$$P_{Total} = \int_0^n P_{section} dx \quad (26)$$

$$P_{max} = \frac{16}{27} * 0.5 * \rho_{air} * v^3 * A \quad (27)$$

$$E(\%) = \frac{P_{Total}}{P_{max}} * 100 \quad (28)$$

$$C_p = \frac{P_{total}}{0.5 * \rho_{air} * v^3 * A} \quad (29)$$

To get the power for each section of the blade first need to calculate Relative speed which can be represented by

$$U_{rel} = v * \frac{1-a}{\sin \emptyset} \quad (30)$$

The following equations can calculate that tangential force and power for each section.

$$F_{tangential} = 0.5 * \rho_{air} * U_{rel}^2 * c * c_x \quad (31)$$

$$P_{section} = \omega * B * t * F_{tangential} * r \quad (32)$$

After computing power for all sections of the blade, values were added to get whole power for the whole blade. Following equations are used to calculate maximum power, efficiency, and coefficient of performance.

$$P_{Total} = \int_0^n P_{section} dx \quad (33)$$

$$P_{max} = \frac{16}{27} * 0.5 * \rho_{air} * v^3 * A \quad (34)$$

$$E(\%) = \frac{P_{Total}}{P_{max}} * 100 \quad (35)$$

$$C_p = \frac{P_{total}}{0.5 * \rho_{air} * v^3 * A} \quad (36)$$

Table 3: performance analysis of designed wind turbine blade

Tip Speed Ratio	Coefficient of performance	Power(kW)	Efficiency (%)
5	0.51	10.31	87.25
5.25	0.4928	9.82	83.16
5.5	0.4962	9.89	83.16
5.75	0.5017	10.00	84.65
6	0.5060	10.08	85.38
6.25	0.5082	10.13	85.75
6.5	0.5089	10.14	85.88
6.75	0.5087	10.14	85.84
7	0.5078	10.12	85.69
7.25	0.5065	10.09	85.46
7.5	0.5047	10.06	85.17
7.75	0.5027	10.02	84.82
8.00	0.5004	9.97	85.17
8.25	0.4979	9.92	84.02
8.5	0.4953	9.87	83.58
8.75	0.4925	9.82	83.11
9	0.4896	9.76	82.62
9.25	0.4866	9.70	82.12
9.5	0.4835	9.64	81.59
9.75	0.4804	9.57	81.06
10	0.4771	9.51	80.51

The coefficient of performance, power, and efficiency was calculated for different tip speed ratios. Figure 10 shows the variation of coefficient of performance for different tip speed ratio.

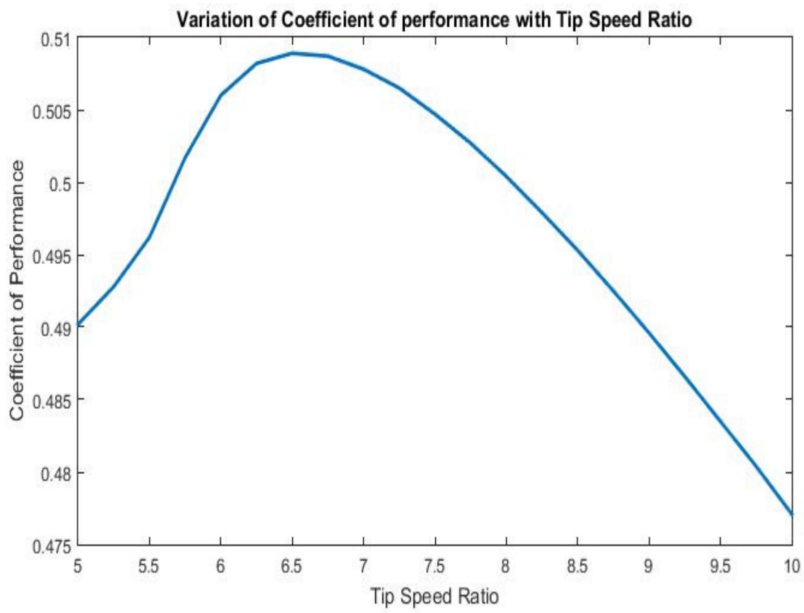


Figure 10: Variation of Coefficient of Performance with Tip Speed Ratio

5. CONCLUSIONS

A small scale horizontal axis wind turbine blade is designed for the wind speed 7 m/s. The three bladed turbine has a diameter of 11 m. The optimum chord lengths and relative angles are designed for different locations along the radial distance with the objective of maximizing the lift to drag ratio as well as blade performance. In this work, the pitch angle is fixed. That's why the twisting of the blade is done according to the optimum angles of attack and relative angles. As it is a small scale wind turbine, only one airfoil is used throughout the blade. From the figure 9, it can be showed that the nature of the curve of performance is pretty much similar to the traditional wind turbine. Here the analysis is done between the tip speed ratios 5 to 10 which is the range for a horizontal axis wind turbine. From the analysis, it is found that the maximum coefficient of performance is 0.5089 for the tip speed ratio 6.5. And in this case, the efficiency and power outputs are 85.88% and 10.14 kW respectively. From the figure, it is noticed that the best tip speed range for this work is 5.75 to 7.75. As tip speed ratio is a function of wind velocity, it can be said that the power output does not deteriorate even the wind velocity fluctuates at a certain range. In future work, different types of airfoil could be used at a time to design the blade, as well as pitch angles, could be varied to get better performance. The analysis was done considering the 2D environment. It would be more realistic and accurate if the analysis will be done by the 3d environment with all components of the wind turbine.

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