Design & Optimization of Small WindTurbine Blade

Mr. Komal M. Garse
Department of Mechanical Engineering, Sinhgad College of Engineering, Pune
kmgarse.scoe@sinhgad.edu

Dr. Dhananjay V. Khankal
Department of Production Engineering, Sinhgad College of Engineering, Pune

Dr. Amar P. Pandhare
Department of Mechanical Engineering, Sinhgad College of Engineering, Pune

ABSTRACT
Small wind turbines are primarily intended for places with low wind speeds and no accessto grid power. As a result, small wind turbines must function under low-wind conditions,which results in a lower operational Reynolds number. A smaller rotor blade diameter reduces Reynolds number, resulting in lower power coefficient and output values.Optimizing the twist of the wind turbine blade is one approach to increase the performance of tiny wind turbines. In this study, the Q-blade programme was used to simulate and optimise a tiny wind turbine blade. The major goal of the project is to improve the power coefficient by optimising the blade twist. Blade element momentum theory (BEM) is used in Q-blade to simulate the performance of the modelled blade. The blade was further tuned for maximum angle of attack after the experimental and simulation findings were compared. It was discovered that the experimental value of maximum Cp was 0.224, while the simulated value was 0.24. It was discovered that theaverage error between field data and simulation was 2.71 percent. The maximal Cp after optimization was 0.333. It was discovered that modifying the blade twist results in a significant increase in power.
.

Keywords: Small wind turbine, Q-blade, Airfoil.

1. INTRODUCTION

Small wind turbines, from less than 1000-watt (1 kW) turbines to 300 kW turbines (CanWEA,2008). The smaller turbines might be as small as the auxiliary power generator of 50 Watts for a boat, caravan or micro cooling unit. The standard IEC-61400-2:2006 defines small wind turbines as wind turbines with a swept rotor area less than 200 m2. A small wind turbine with a maximum power output of 50 kW was defined by Clausen and Wood (2000) and sub-divided into three categories: micro turbines (maximum 1 kW), mid ranges (larger than micro turbines and smaller than mini ones), generally 1 kW to 5 kW, and mini turbines with an output greater than 20 kW. There are numerous situations in which we can use small wind turbines for household and agricultural purposes, for example. Depending on the axis of rotation, these turbines are classed as Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind turbines (VA WT). In most applications, HAWT are commonly utilised with a wind speed and a turbine

diameter square power generation, which means that power generated at any time is a function of the wind speed and turbine swept area. The power coefficient of smallwind turbines is 0.25 or higher compared to the huge turbines with a power coefficient (Cp) ofabout 0.45 (Gross & Fasel,2011). But aerodynamic optimization of the rotor blades with optimization of chord and twist distribution, aerofoil selection and the speed ratio can enhancethe power coefficient for tiny wind turbine.

A study of the performance of small wind turbines suggests that the measured power coefficient for small turbines is approximately 12% -20% (Gross & Fasel,2011). The low aerodynamic performance of the blades means that the power coefficient is low, such as the non-optimum alternator design, wind load controller and topology of loading. The power coefficient must therefore be maximised in order to boost the performance of a tiny wind turbine. The blade must therefore be adjusted for maximum power coefficient value.

Problem Statement

Having known that power coefficient of small wind turbines lies in the range from 0.25 to 0.1, it is needed to improvise their Cp by optimizing the operating variables. Hence the problem being addressed is to Design and optimization of 3.2 kw small wind turbine blade.

2. DESIGN & ANALYSIS

Blade Design and Optimization

Method of dynamic blade element (BEM). BEM brings together dynamic theory or disc actuator theory which describes local blade occurrences. The blade is divided into a few components of the blade. The BEM theory comprises two methods to the operation of wind turbines. The first way is to use a dynamic balancing in a spinning ring tube by a turbine. The second is to investigate the lifting forces and the drag coefficients generated by the aerofoil in various regions of the blade. These two methods present a number of equations that can be resolved successfully.

Iteration Procedure

The iteration variable in BEM method are axial and radial induction factors respectively which are given by following equation

$$a = \left(\frac{4sin\emptyset^2}{\sigma C_n} + 1\right)^{-1}$$

$$a' = \left(\frac{4sin\emptyset cos\emptyset}{\sigma C_t} - 1\right)^{-1}$$

where $\emptyset$ is inflow angle, Ct and Cn the tangential and normal force coefficients and σ is rotor solidity

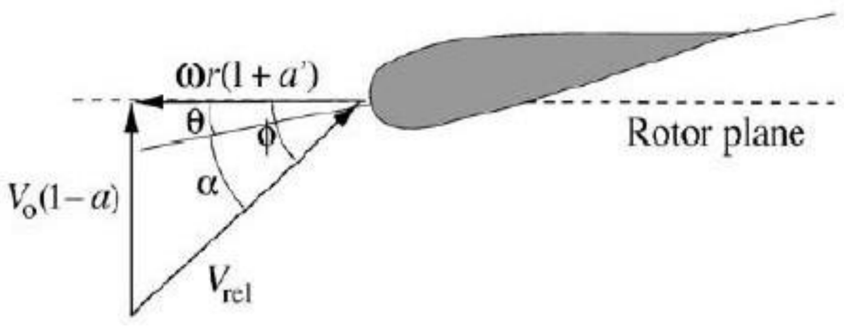

Fig.1. Velocities at rotor plane (Marten 2013).

If the induction factors are known, it possible to compute the inflow angle ($\emptyset$). Which gives the angle of attack the angle between the aerofoil chord line and the relative windspeed experienced by the rotating blade

$$\alpha = \varphi - \theta$$

where α is angle of attack, θ is angle of twist.

The aerofoil's lifting and drag forces can be calculated by knowing the angle of attack. New induction factors from these forces can be calculated and compared to the initial induction factors. Iteration then goes on to converge values and the following element can be calculated.

Blade Geometry

The blade design module allows rotors and blades to be designed in an efficient and straightforward way. The aerophiles that spread over different radial (HAWT) or height (VAWT) regions of a blade within the aerophile module constitute a rotor blade. The blade is split into 100 elements, and for each blade element, the following parameters must be given:

Position (m)

Chord (m)

Twist angle (degrees)

For the design and simulation of blade the information in Table. 1 has been used in current project to provide the geometry of the blade for further analysis.

Table.1. Geometry of existing blade.

Position (m)	Chord (m)	Twist (Degree)
0.57375	1.670	0
0.6615	1.582	0
0.74925	1.494	0
0.83925	1.406	0
0.927	1.319	0
1.01475	1.231	0
1.1025	1.143	0
1.19025	1.055	0
1.28025	0.967	0
1.368	0.879	0
1.45575	0.791	0
1.5435	0.703	0
1.6335	0.615	0
1.72125	0.527	0
1.809	0.440	0
1.89675	0.352	0
1.9845	0.264	0
2.0745	0.176	0
2.16	0.088	0
2.25	0.000	0

Fig.2 shows the 3-D blade model generated in Q-blade. Then rotor BEM simulation was performed to evaluate the performance of the turbine.

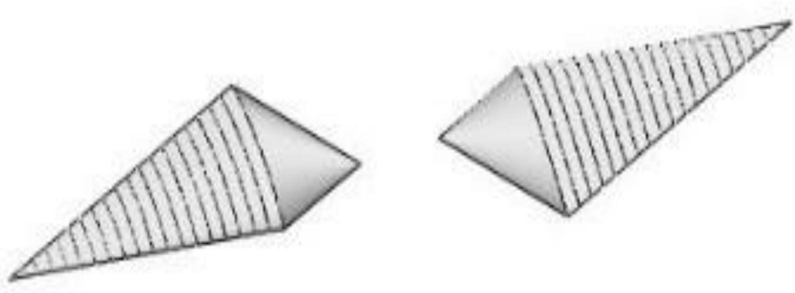

Fig. 2. Existing blade model in Q-blade.

Blade Optimization

The designed blade is optimized in blade optimize module in Q-blade. The user has to choose a tip speed ratio λ_0 to optimize for, and the positions of blade that are to be optimized. From this tip speed ratio, an assumed inflow angle is computed for every section

$$\alpha_{loc} = \tan^{-1}\left(\frac{1}{\lambda_{0,loc}}\frac{2}{3}\right)$$

The designed blade is optimized for tip speed ratio of 4 and the optimum value of C_l/C_d at which angle of attack is 4^0 as shown in Fig.2. The Optimize lift/drag sets the twist to blade, at the specified $\lambda_{0,loc}$ at which the blade section operates, to an angle of attack that yields the highest glide ratio. The changes in the geometry of the optimised blade is given in Table.2 and the model of optimized blade is shown in Fig.3. It is seen that after optimising the blade a twist of 18.830 to 1.460 was set.

Then again, the BEM simulation was performed for optimized blade and the results were compared with the non-optimized blade which is discussed in next section.

Table.2. Geometry of optimized Blade at α=4 degree.

Position (m)	Chord (m)	Twist (degree)
0.57375	1.670	18.8311
0.6615	1.582	16.5662
0.74925	1.494	14.6351
0.83925	1.406	12.9332
0.927	1.319	11.4943
1.01475	1.231	10.2343
1.1025	1.143	9.12257
1.19025	1.055	8.13524
1.28025	0.967	7.23162
1.368	0.879	6.44102
1.45575	0.791	5.72694
1.5435	0.703	5.07897
1.6335	0.615	4.47404
1.72125	0.527	3.93504
1.809	0.440	3.44009
1.89675	0.352	2.98407
1.9845	0.264	2.56262
2.0745	0.176	2.16235

2.16	0.088	1.80894
2.25	0.000	1.46232

Fig. 3. Optimized blade model in Q-blade

3. RESULTS

The results obtain from BEM simulation for existing blade (present simulation) is compared with experimental data provided by the manufacturer. Fig. 4, Fig. 5, Fig.6 shows the CR-windspeed curve of existing blade and for optimized blade.

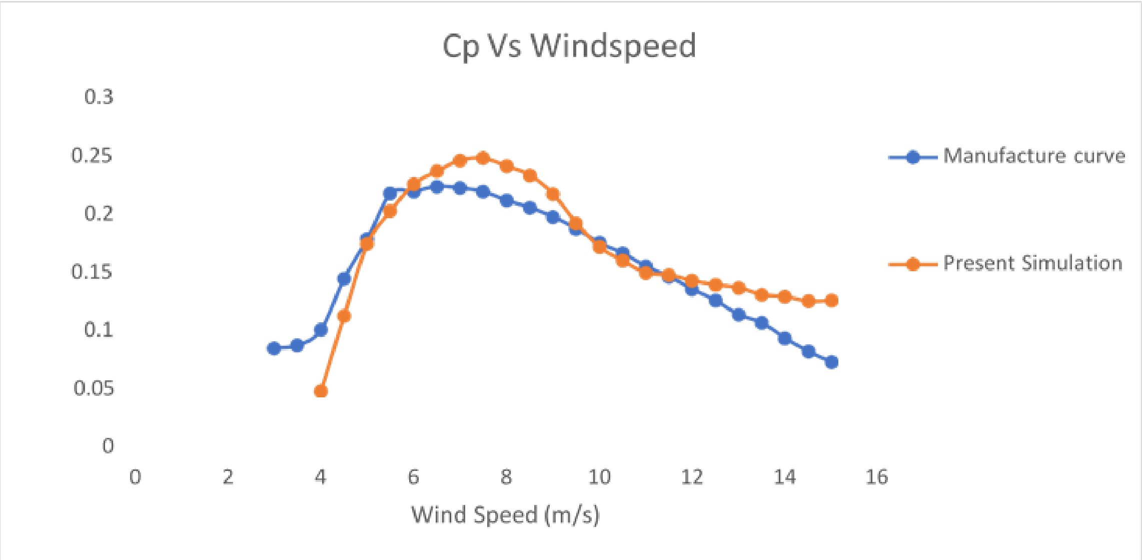

Fig. 4. C_R- windspeed curve of existing blade.

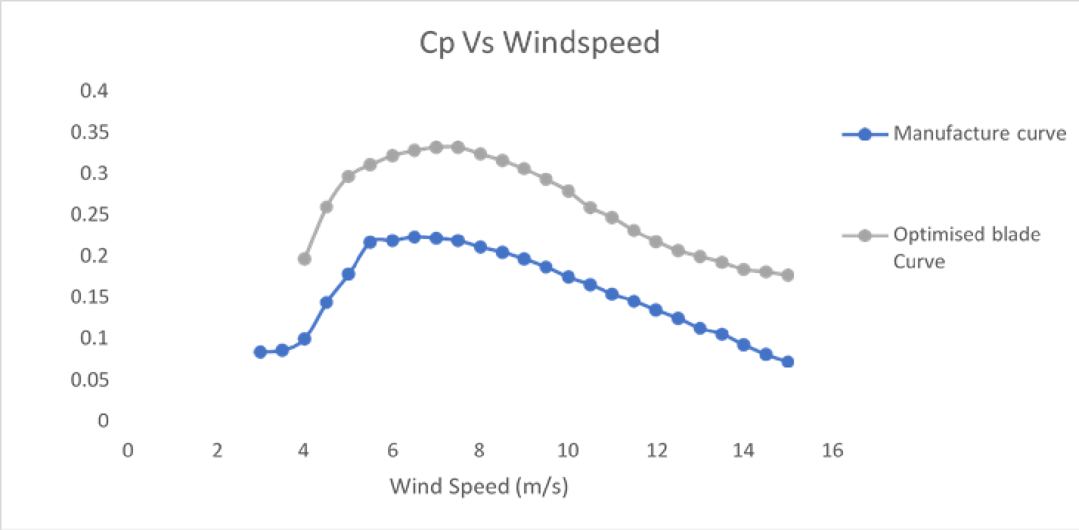

Fig. 5. C_R- windspeed curve for optimized blade.

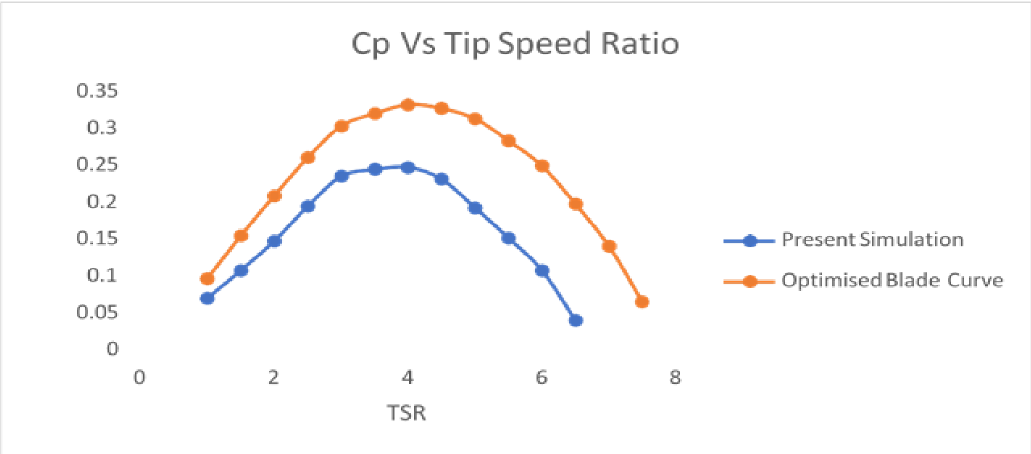

Fig. 6. C_R-λ curve

From Fig. 5. it is noticed that C_p varies significantly with wind speed, the maximum value of power coefficient occurs around the wind speed of range 5 m/s to 10 m/s. For present simulation the maximum value of C_p=0.24 whereas the experimental value of maximum C_p=0.224. The values of power coefficient are in close agreement with experimental results provided by manufacturer. The average error between experimental results and present simulation was found to be 2.71%. In Fig.6. the optimised blade results are compared with the existing blade results and found that power coefficient is improved in case of optimised blade with twist. The maximum C_p=0.33 was obtained in case of optimised blade design.

Also, from Fig. 7 it is seen that the maximum power coefficient lies in between TSR of 3-5in case of optimized and existing blade (present simulation). The average error between experimental results and present simulation was found to be 2.71%.

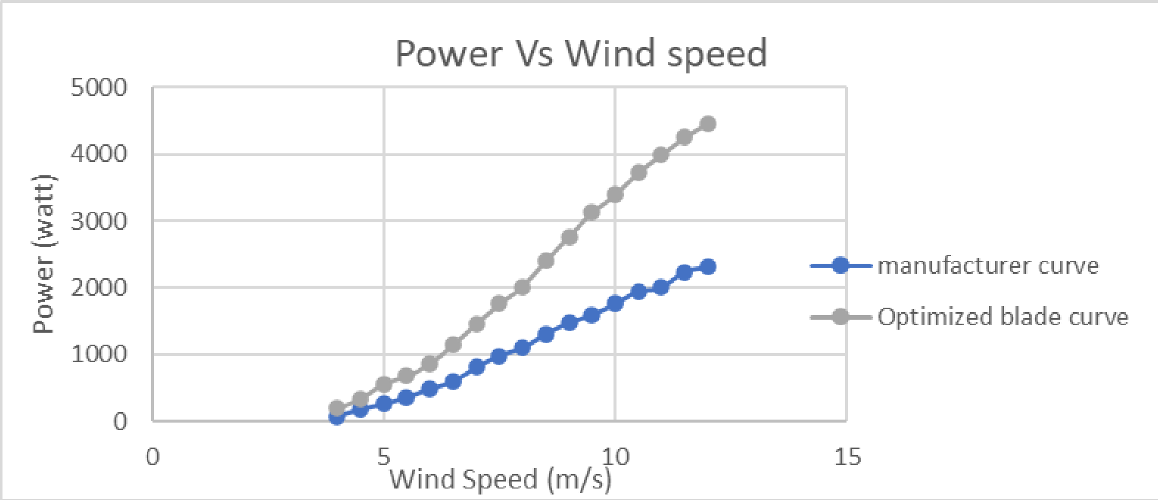

Fig. 7. Power-wind speed curve

The production of wind turbines increases with the wind speed as seen in Fig.7 . The present blade output experimental results are compared to the optimised blade output. The power output of the existing blade was 2000 W, with a rated wind speed of 11 m/s and an optimised blade of 3984 W. The power output was discovered to be improved by twisting the blade at the best angle of attack. The power output for the enhanced blade is 1,5-1,6 times the power output for the old blade.

4. CONCLUSION

The main aim of the work was to design and optimize a 3.2 kw small wind turbine blade. The work has been carried out using an open source software Q-blade. The existing blade of WHISPER 500 wind turbine manufactured by Wish Energy Pvt Ltd was simulated and optimised to improve its power coefficient. The experimental results provided by manufacturer are compared with the simulation result from Q-blade software. The results found were in close agreement to experimental data. The average error reported in experimental and simulation results was 2.71%. The error in results might occurred due to fixed Reynolds number (Re=200000) taken in simulation. The coefficient of power in case of Q-blade simulation was found to be 0.24 and the experimental value of manufacturer is 0.224. Further the existing blade is optimized for maximum value of lift/drag at angle of attack 4 degrees. The results obtained showed that the power coefficient improved to 0.33 in case on optimized blade. It was found that by giving twist to blade for optimum angle of attack the power output increased. The power output obtained in case of optimized blade is 1.5-1.6 times the power output obtained in case of existing blade.

5. REFERENCES

1) A. Gross, Fasel HF, "Numerical Investigation of Different Wind Turbine Airfoils", *49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*., The University of Arizona, Tucson, Orlando, Florida; 2011.
2) Chalothorn Thumthae, "Optimum Blade Profiles for a variable-Speed Wind Turbine in Low Wind Area" *Elsevier-Energy Procedia 2015,1876-6102.*
3) Clausen, P.D., and Wood, D.H., "Recent Advances in Small Wind Turbine Technology," *Wind Engineering*, Vol. 24, No. 3, 2000, pp. 189-201.
4) David Marten and Juliane Wendler, "Q-blade Guidelines v0.6", Tu-Berlin, Jan 2013.
5) Duquette M M, Visser K D, "Numerical Implications of Solidity and Blade Number on Rotor Performance of Horizontal Axis Wind Turbines", *Journal of Solar Energy Engineering*, 2003; 125(4) pp.425-432
6) Francesco Grasso, "Design of Family of new advanced airfoils for low wind class turbines", *Journal of Physics: Conf. Series. 555 012044, (2014).*
7) Freere P, Sacher M, Derricott J, Hanson B, "A Low-Cost Wind Turbine and Blade Performance", *Wind Engineering*, 2010; 34(3), pp. 289-302.
8) J. Bilbao, E. Bravo O, O. Garcia, C. Varela, M. Rodriguez, P. Gonzalez., "Blade aerodynamic design and analysis as first step to achieve the expected power performance of a small wind turbine", *IJTPE Journal*, Volume 7, Pg. 42-46, 2015.
9) M. Predescu, A. Bejinariu, O. Mitroi, A. Nedelcu., "Influence of the Number of Blades on the Mechanical Power Curve of Wind Turbines", *International Conference on Renewable Energies and Power Quality*, Valencia (Spain), 2009.
10) Maalawai K. Y and Badr M. A., "A practical Approach for selecting optimum wind rotors", Renewable Energy,28, pp.803-822, (2003).
11) Mingwei Ge, De Tian, Ying Deng., "Reynolds Number Effect on the Optimization of a Wind Turbine Blade for Maximum Aerodynamic Efficiency", *Journal of Energy Engineering*, Vol. 142, Issue 1, March 2016.
12) Peter J. Schubel and Richard J. Crossley, "Wind Turbine Blade Design" *Energies 2012, 5, 3425- 3449.*
13) R. Lanzafame, M. Messina., Power Curve Control in Micro Wind Turbine Design., *Elsevier-Energy* 3, 2010; 556-561.
14) Refan M, Hangan H, "Aerodynamic Performance of Small Horizontal Axis Wind Turbine", *Journal of Solar Energy Engineering*, 2012; 134(2) 021013-021013.
15) Ronit K. Singh and M. Rafiuddin Ahmed, "Blade Design and Performance Testing of Small Wind Rotor for Low Wind Speed Applications", *Renewable Energy 50 (2013) 812-819.*
16) Wright A.K and Wood D. H., "The starting and low wind speed behaviour of small Horizontal Axis Wind Turbines," *Journal of Wind Engineering and Industrial Aerodynamics*, Vol.92, pp.1265-1279 (2004)